The status of particle CT at DKFZ and UiB

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[8] Wigner Research Centre for Physics, Budapest, Hungary
[9]] Heidleberg Ion-Beam Thearpy Center (HIT), Heidelberg, Germany

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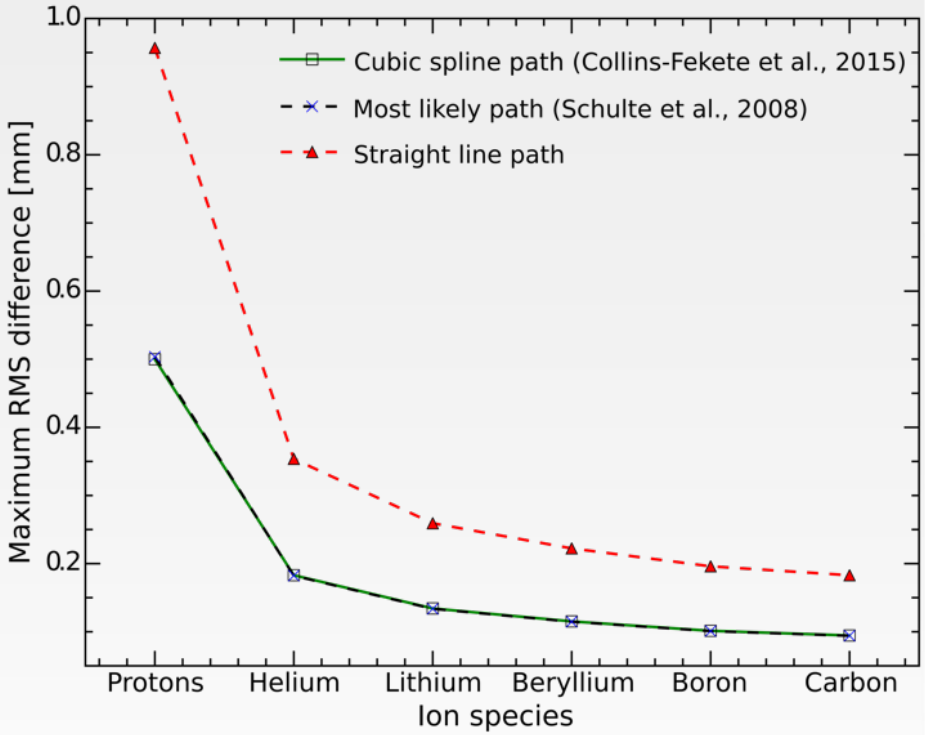
Summary

- Introduction
- HeCT at DKFZ
  - ➡ Simulation and experiment with the pCT scanner at HIT
  - ➡ Filtering fragments (by Lennart Volz)

- The UiB pCT project
  - ➡ Fist experiment at HIT

Helium imaging: why?

- Lower multiple Coulomb scattering compared to protons
  - ➡ Higher achievable spatial resolution[1,2]
- Lower energy/range straggling compared to protons
  - ➡ Higher achievable precision[3]
- Lower dose and less fragmentation compared to heavier ions[4]
- Rising interest in helium ion therapy[4]



[1] Collins-Fekte et al. (2017);
[2] Piersimoni et al. (2018);
[3] Gehrke et al. (2018);
[4] Mairani et al. (2016)

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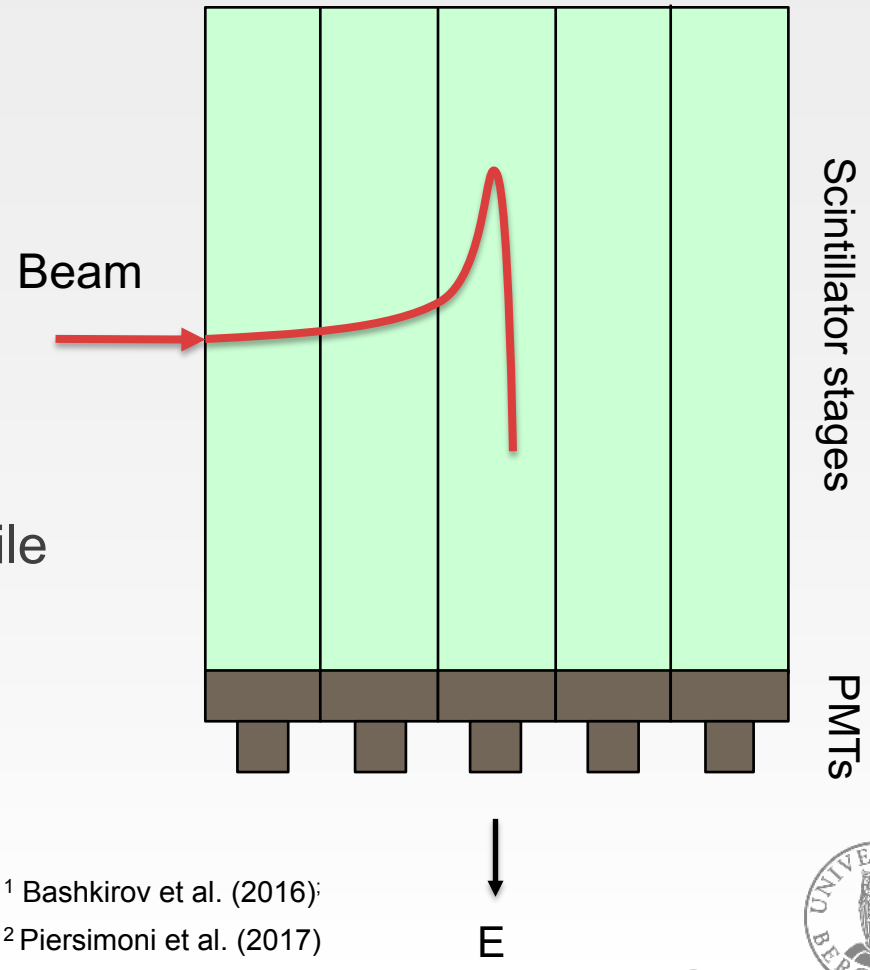
HeCT at DKFZ

Experiment at HIT

December 2016 – January 2017

pCT scanner multistage energy detector

- 5 stage energy/range detector[1]
- Plastic scintillator material[1,2]
  RSP_{exp}= 1.030±0.003;
  RSP_{sim}= 1.043
- Particle detection rate up to ~1MHz at less than 5% event-pile up
- Calibration to WET using polystyrene object of known thickness[1,2]



[1] Bashkirov et al. (2016)
[2] Piersimoni et al. (2017)

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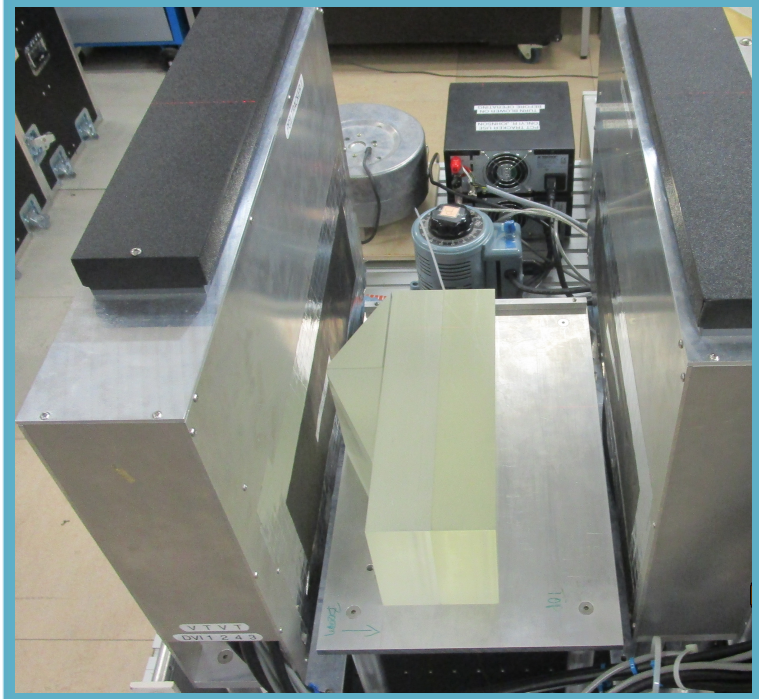
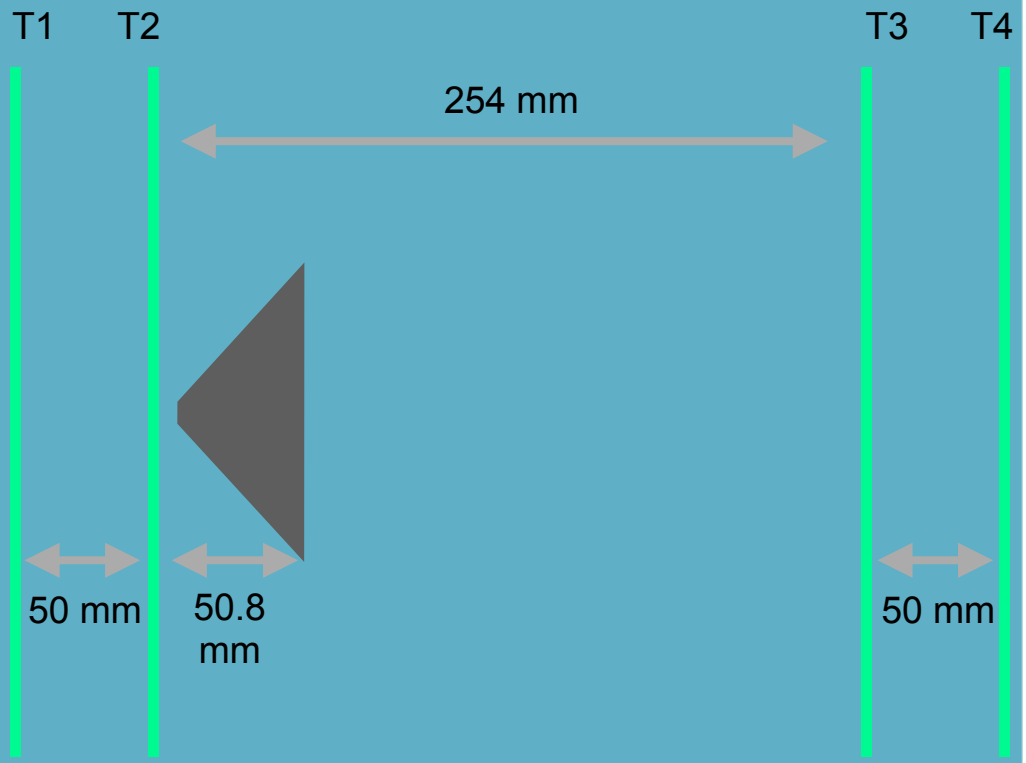
Energy to WEPL Calibration





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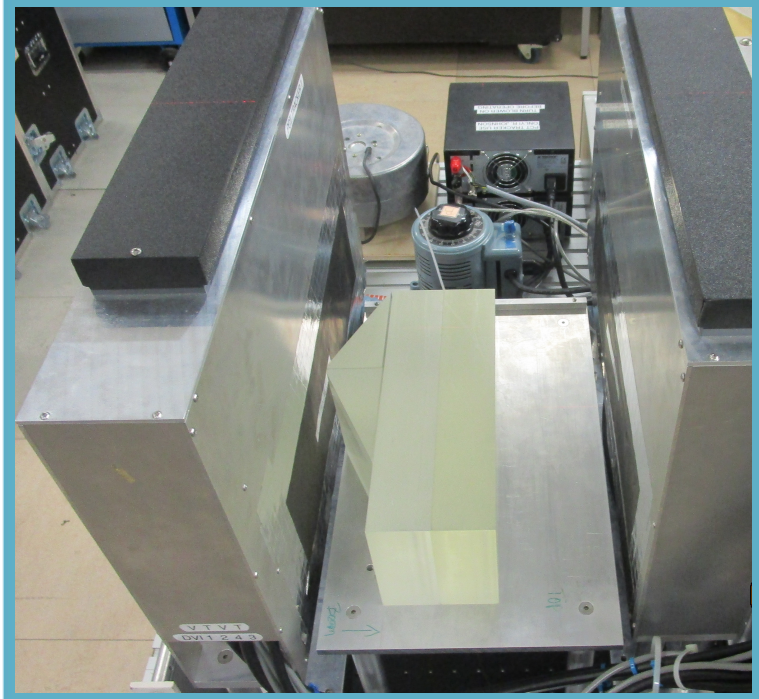

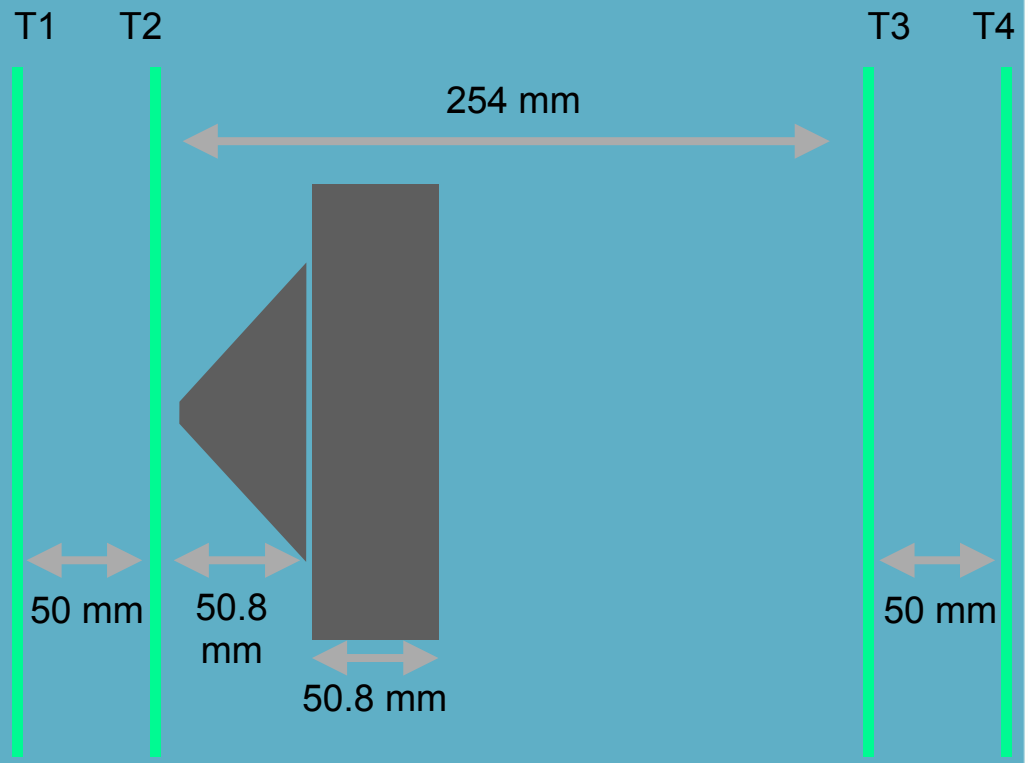

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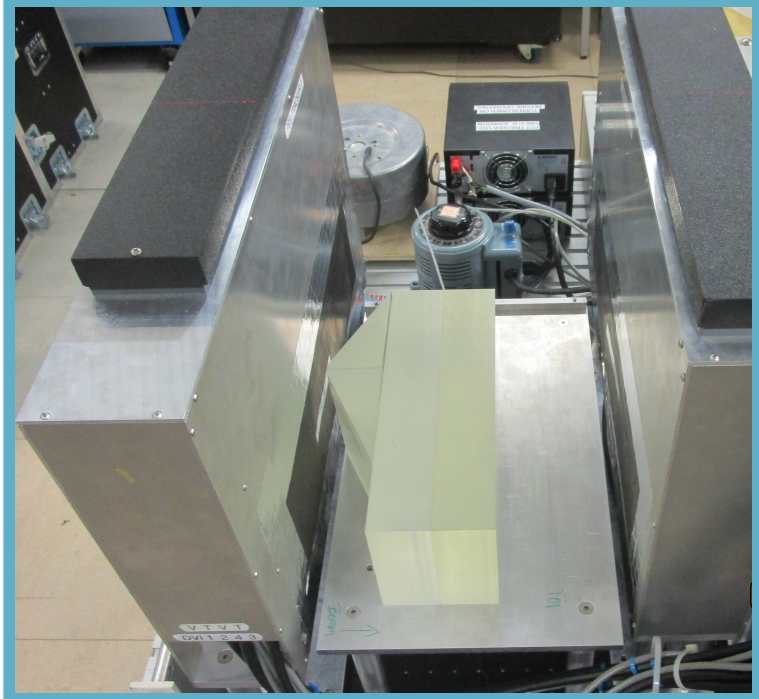

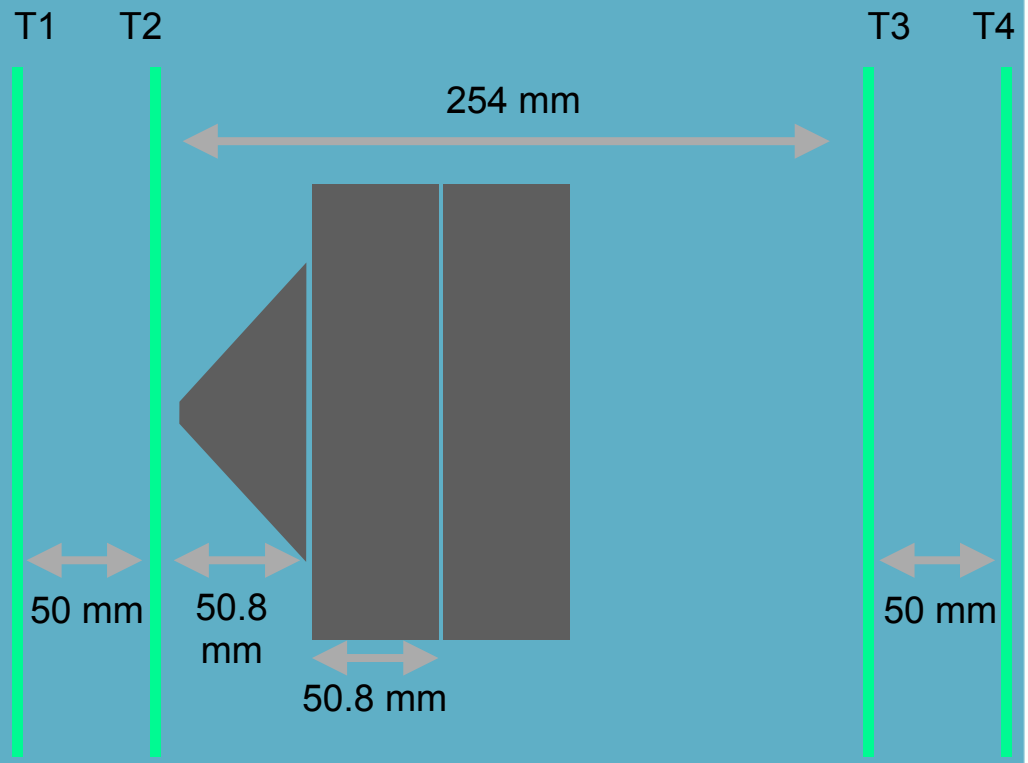

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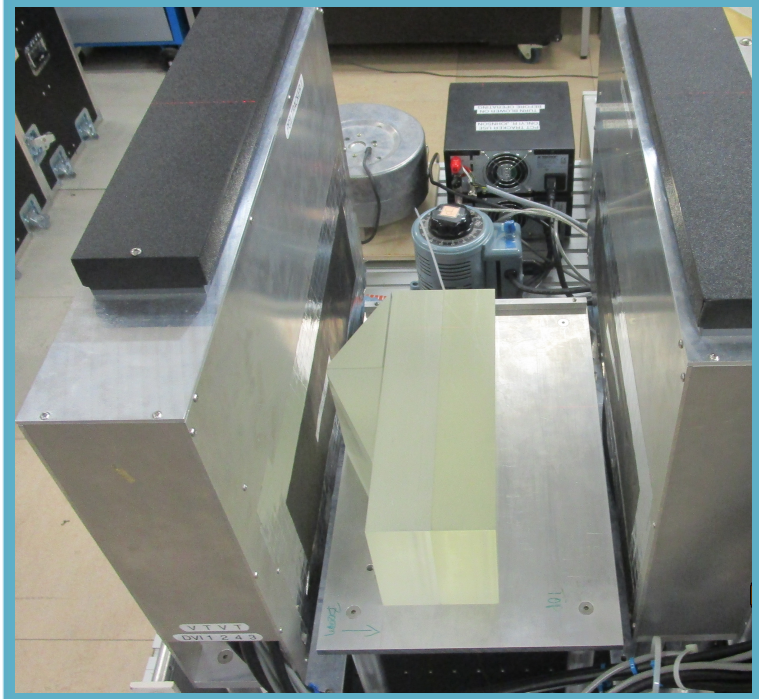

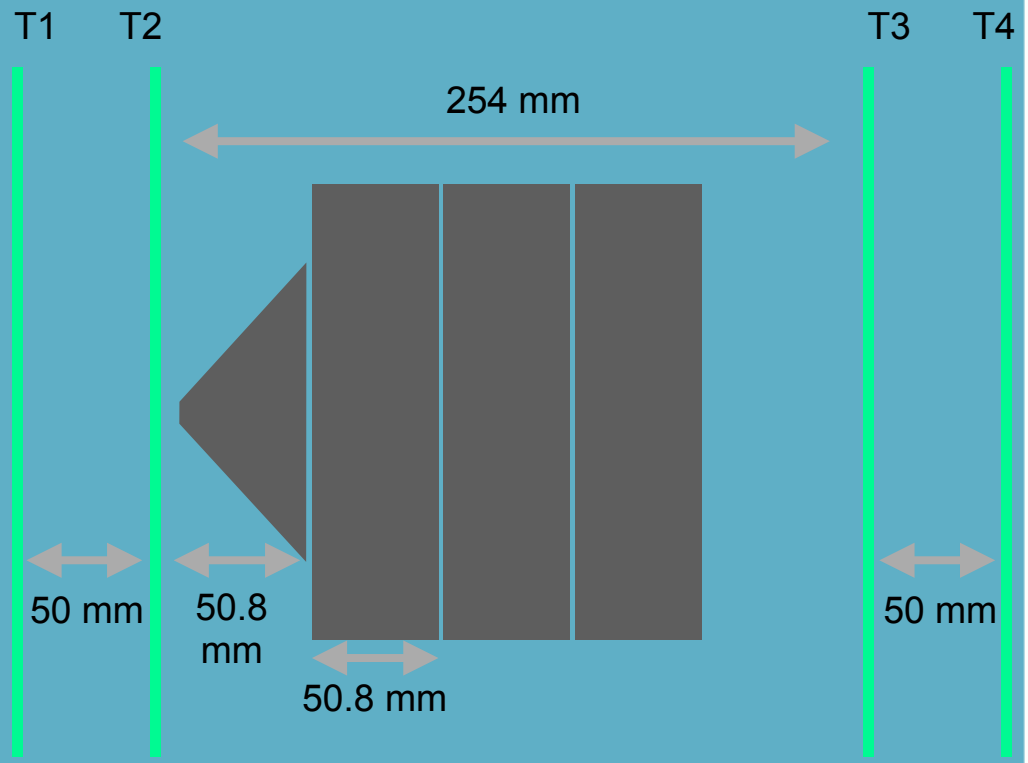

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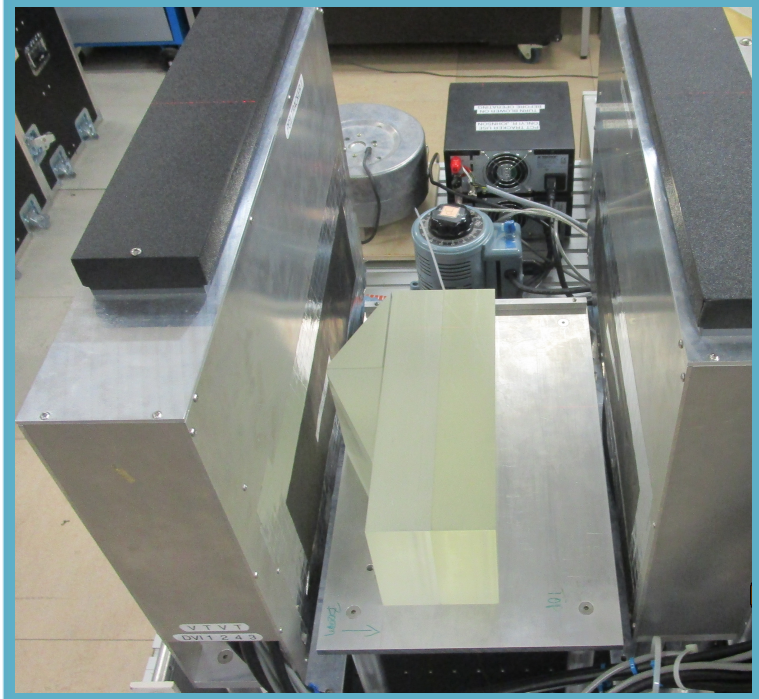

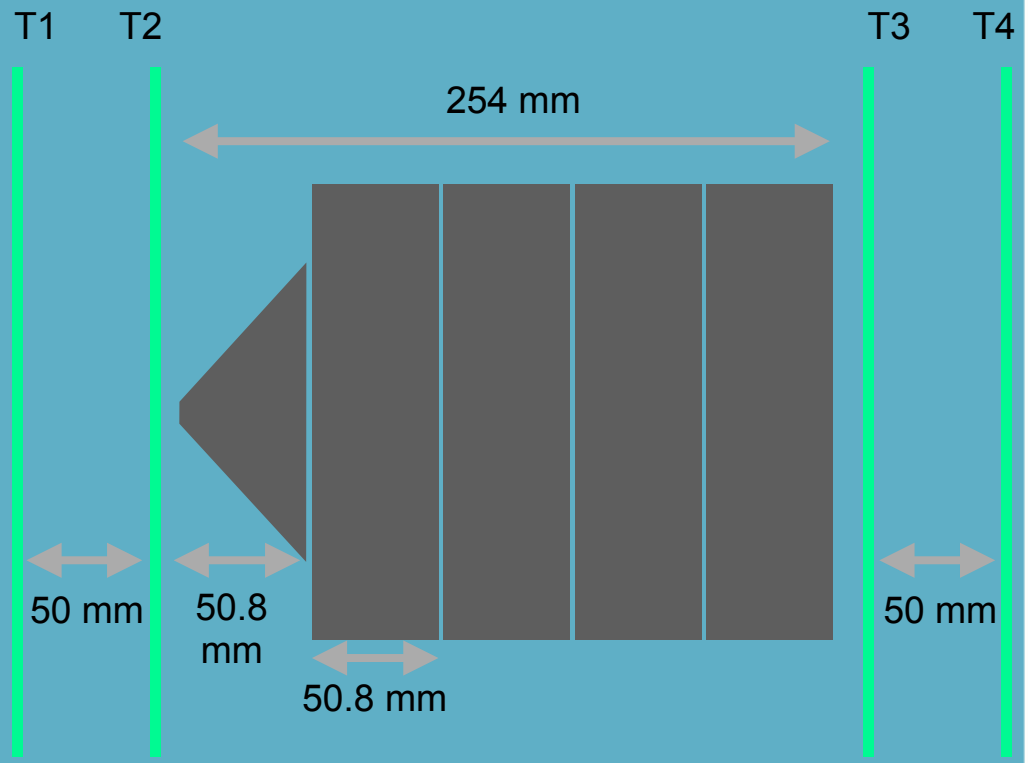

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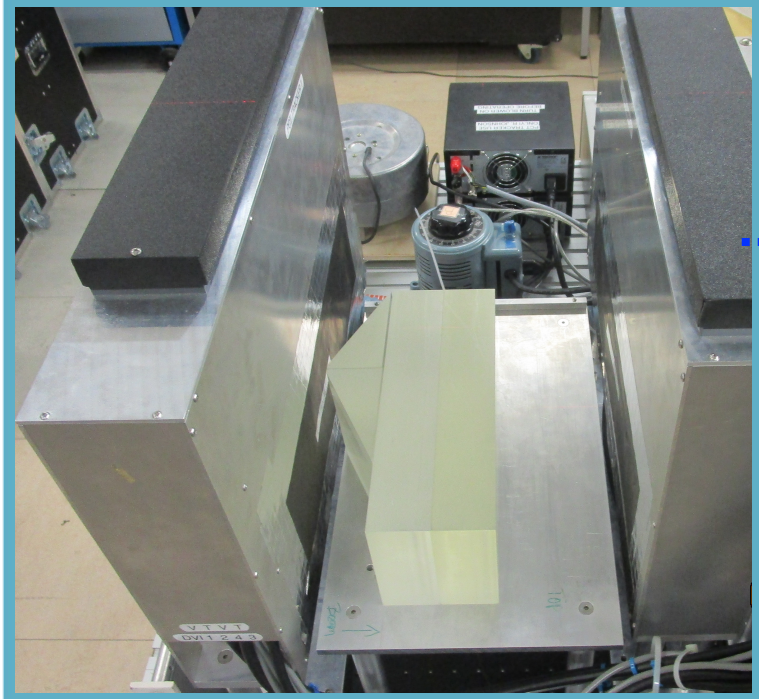
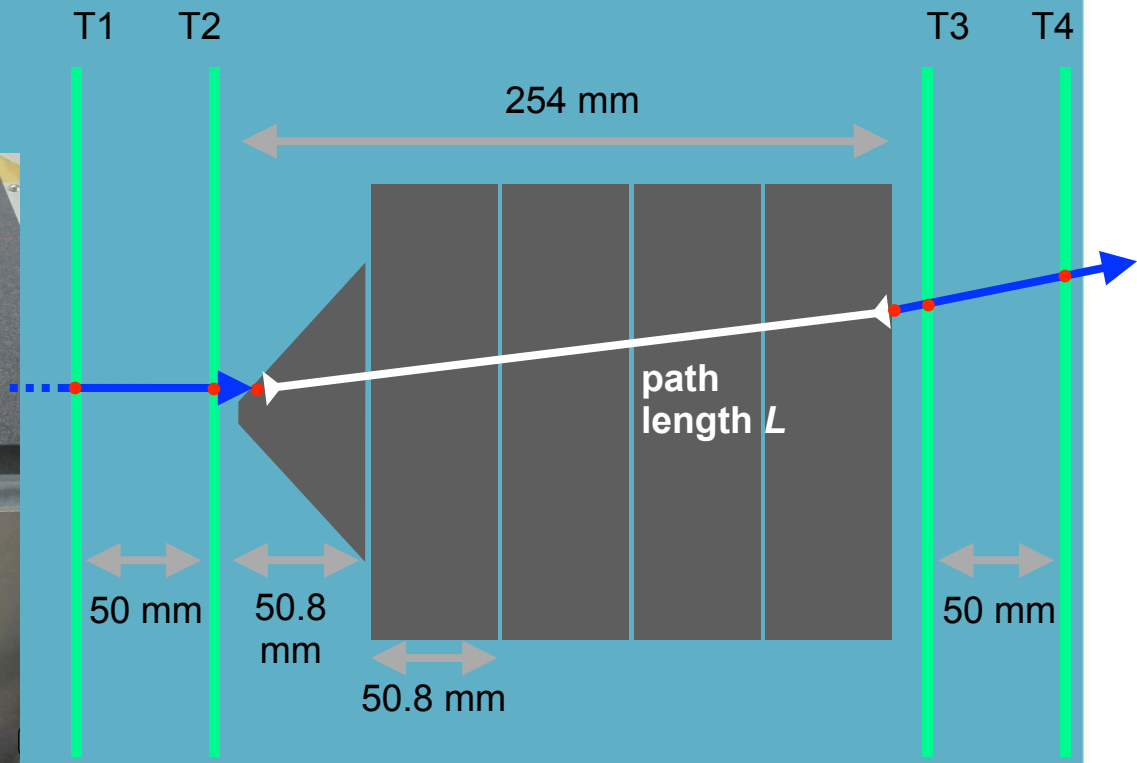
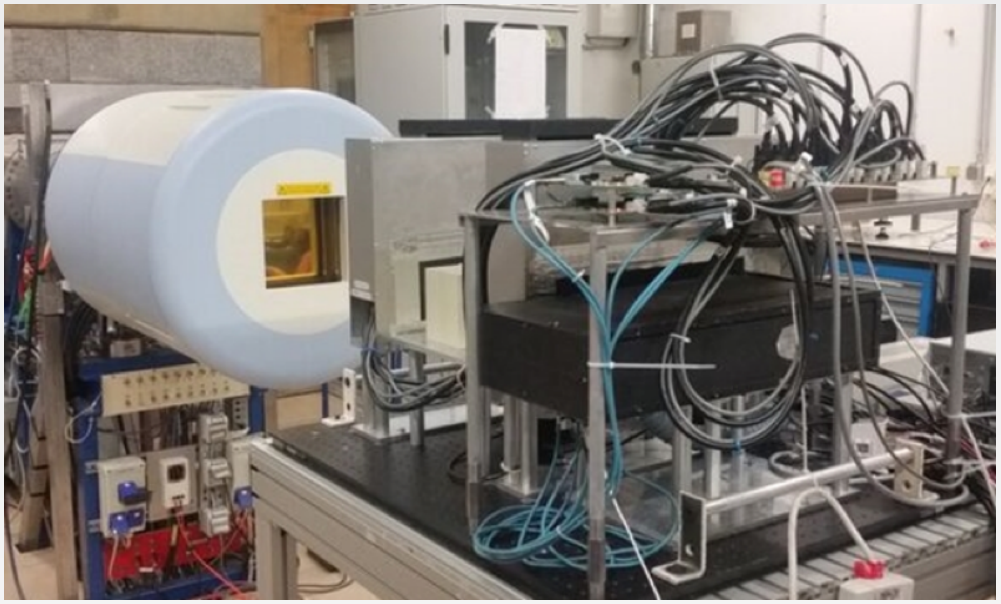




Beam settings and scanning experiment



- Experiments conducted at the beam line dedicated to experiments at HIT [1]
- Experiment: Raster scanning (10.8 mm FWHM spots)

- ~$2.5 \cdot 10^6$ part./proj. (~800kHz)
- E_{in}=200 MeV/u
- 90 projections 4° step[2]

[1] Harberer et al. (2004);

[2] Plautz et al. (2016)

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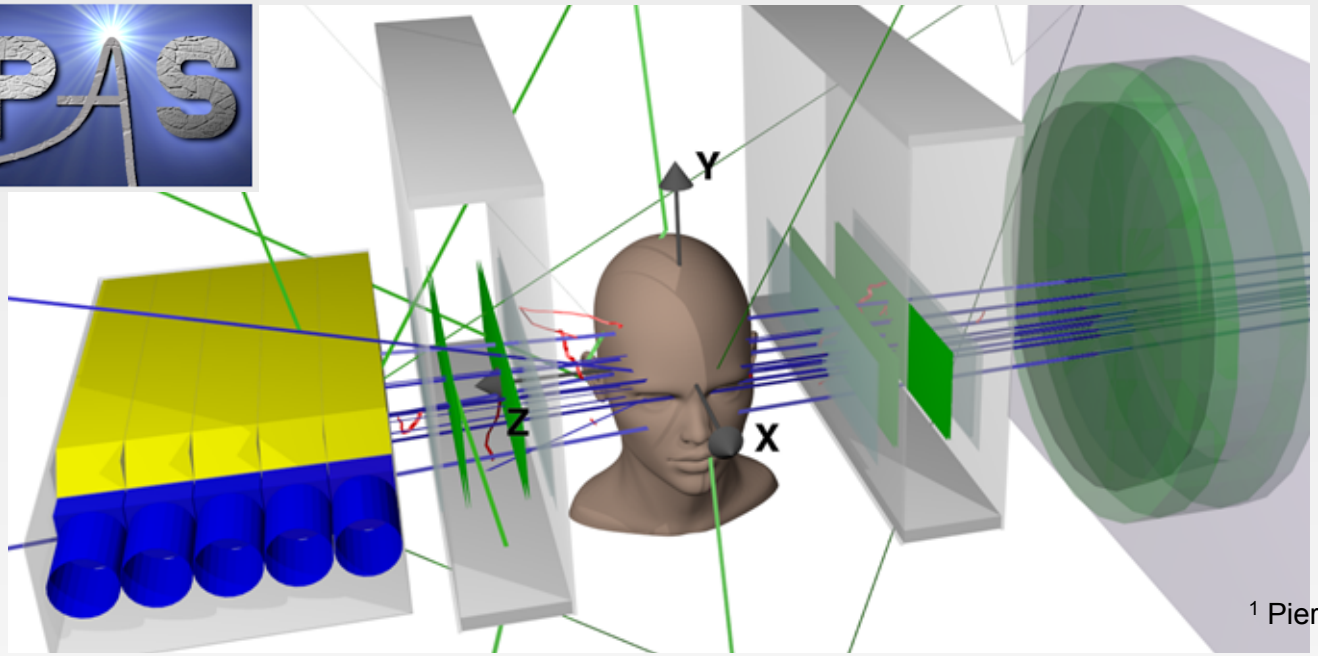
Monte Carlo simulation



[1] Piersimoni et al. (2017)

- TOPAS 2.0
  based on Geant4 10.01.02
- Physics list activated for both electromagnetic and nuclear processes

- pCT geometry for tracker system
- Full simulation of the MSS
- Rectangular flat source
  9x36 cm^2
  energy 200 MeV/u

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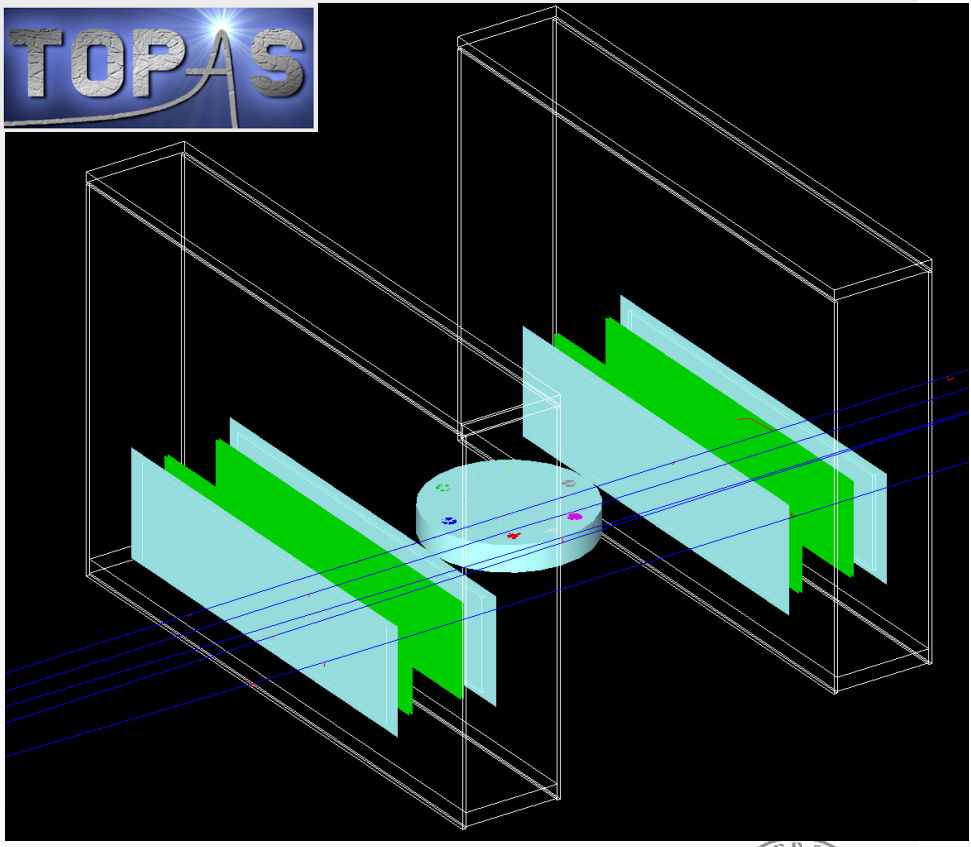
pCT scanner multistage energy detector

- pCT geometry for tracker system
- Ideal energy detector: energy scored directly on the trackers
- Ideal beam:
  rectangular flat source
  9x36 cm^2
  energy 200 MeV/u



Piersimoni et al. (2018)

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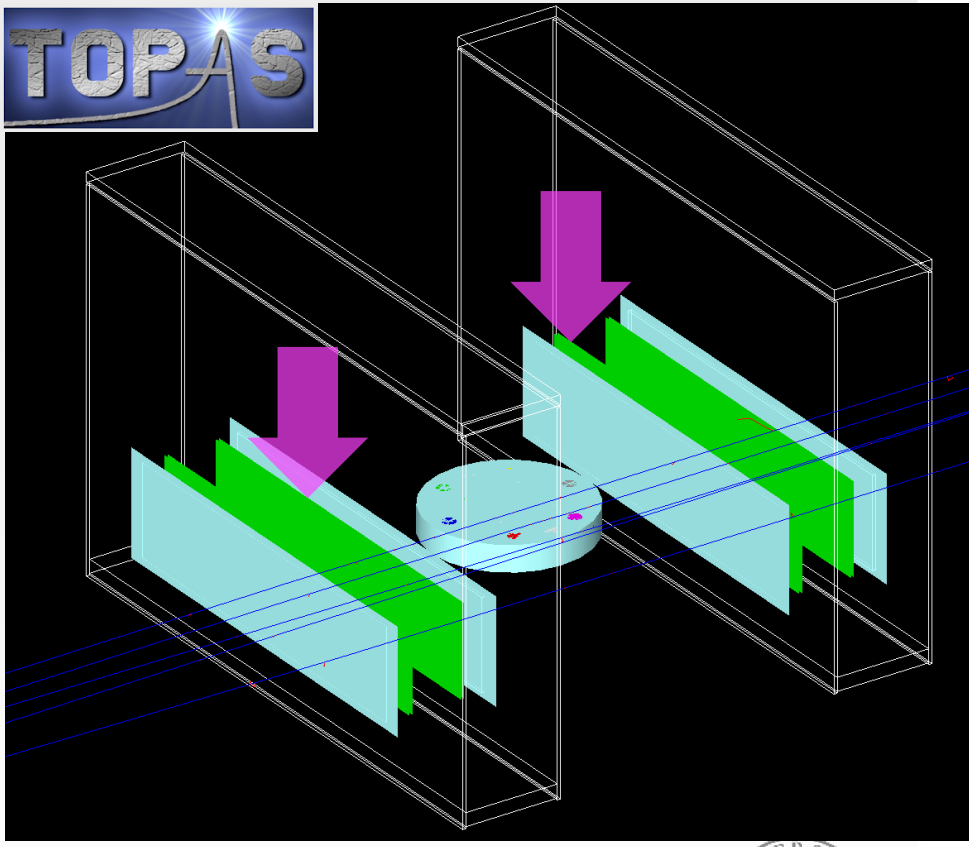

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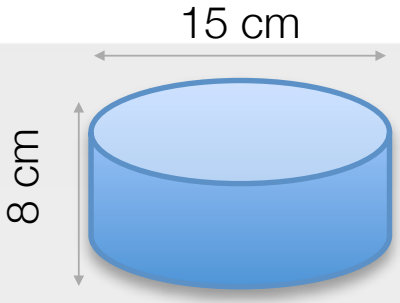
Simulated only phantom



- Water cylinder 15.0 cm diameter, 8.0 cm height
- Insert Phantom 1 (IP1): 5 inserts of 3 cm diameter made of different materials

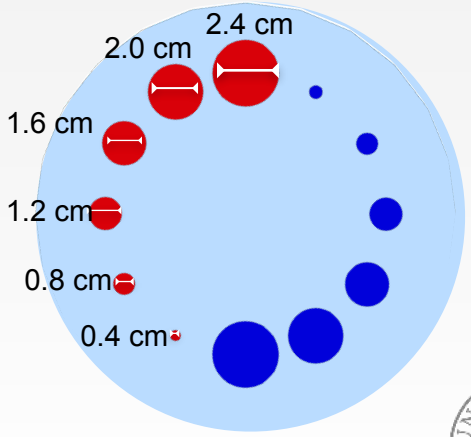
Cortical bone density: 1.75 g/cm^3

Brain tissue density: 1.07 g/cm^3

Trabecular bone density: 1.13 g/cm^3

Tooth dentine density: 1.66 g/cm^3

Tooth enamel density: 2.04 g/cm^3



Piersimoni et al. (2017)

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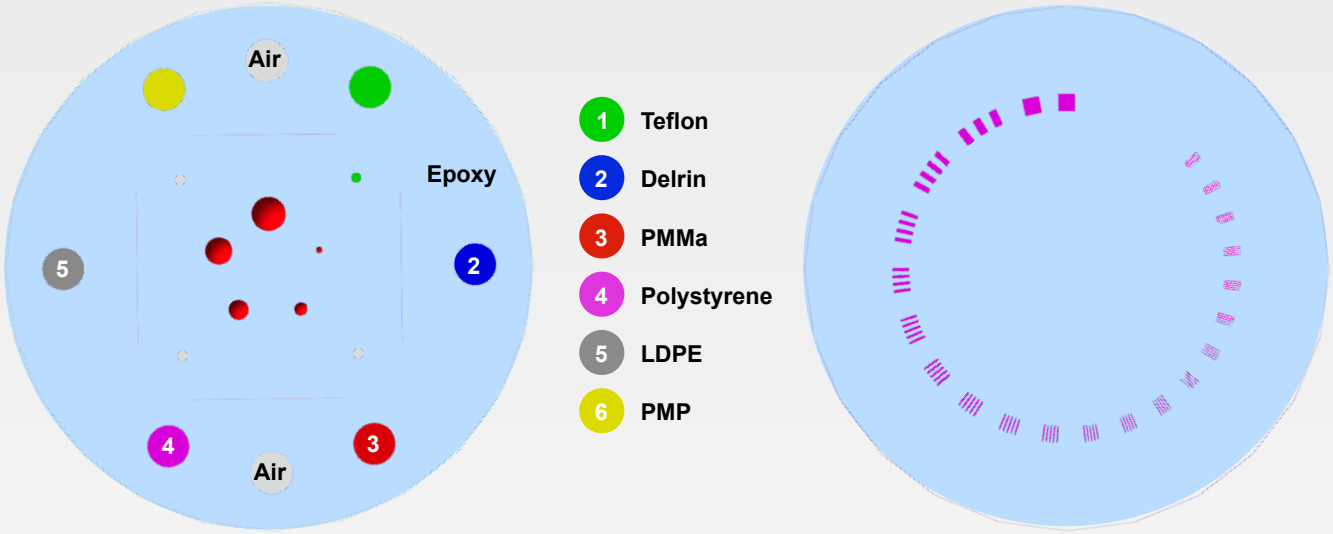
CATPHAN phantoms



- Sensitometry module (CTP404): 15 cm diameter, 4 cm thickness, 8 cylindrical inserts of 1.22 cm diameter

*Catphan® 600 series
The Phantom Laboratory, Salem, New York, USA

- High resolution module (CTP528): 15 cm diameter, 4 cm thickness, 21 groups of high-contrast aluminum bars ranging from 1 to 21 line pairs per cm

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Results for the ideal simulation

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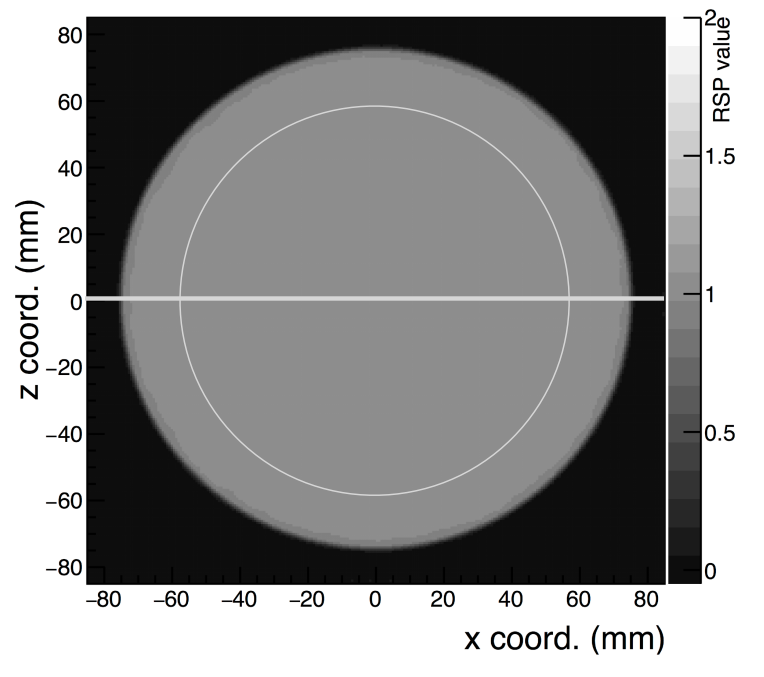
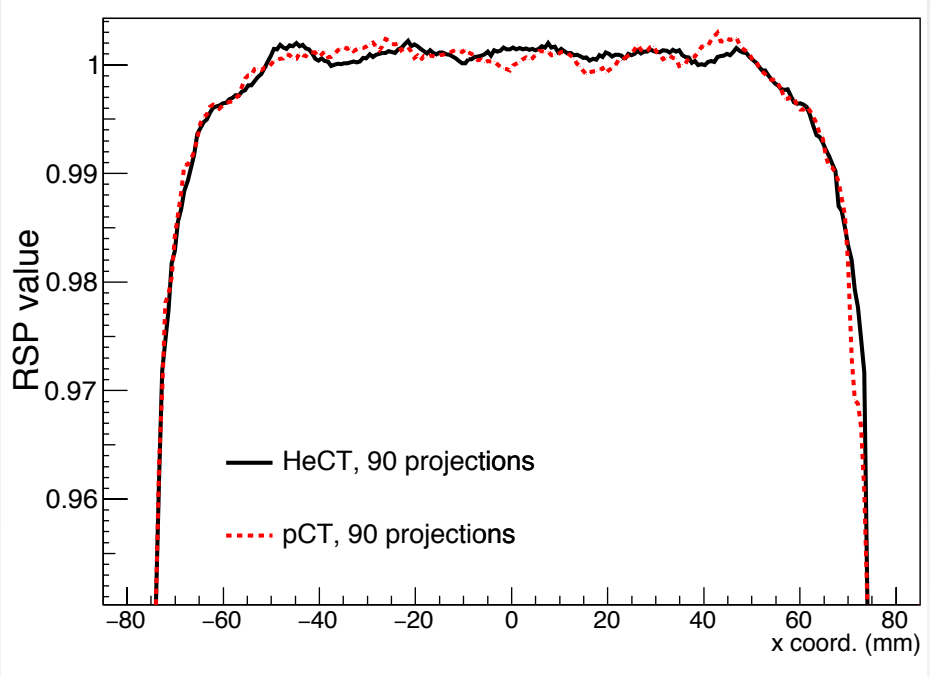
Water phantom



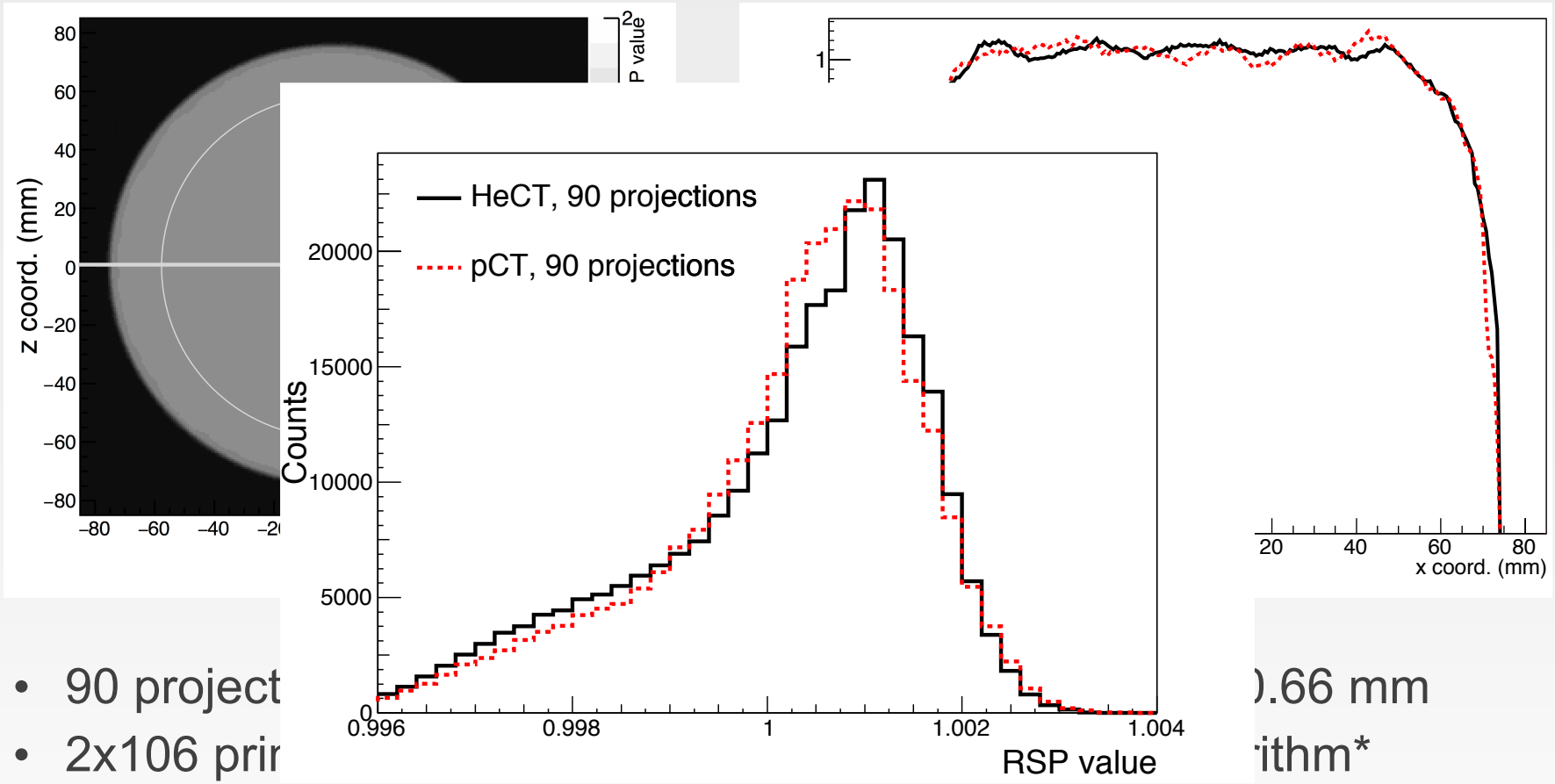


- 90 projections, 4º step
- 2x106 primaries per projection
- 1.25 mm slice thickness

- 256x256 pixels, 0.66 mm
- TVS-DROP algorithm*
- 6 iterations, 40 blocks

*Penfold et al., 2010

Water phantom



- 90 project … .66 mm
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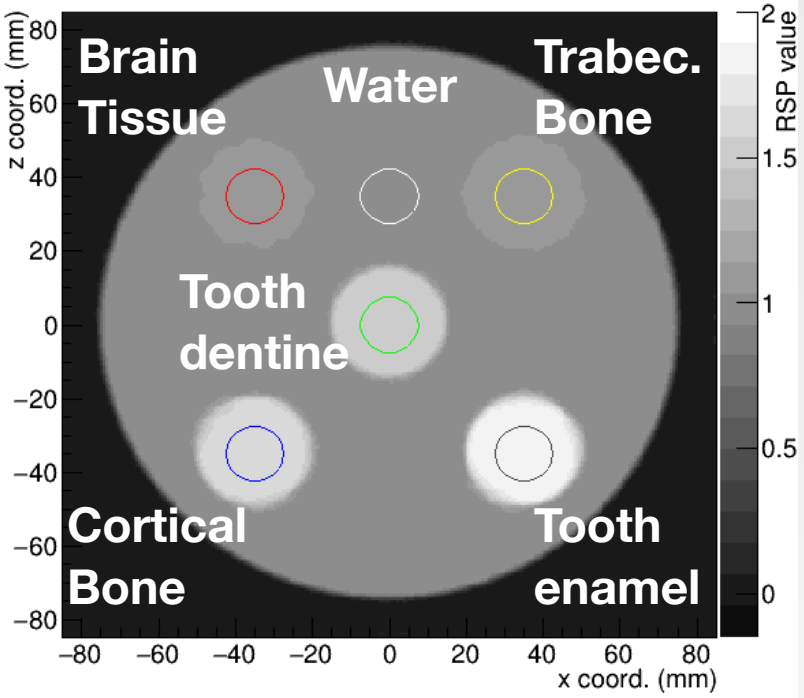
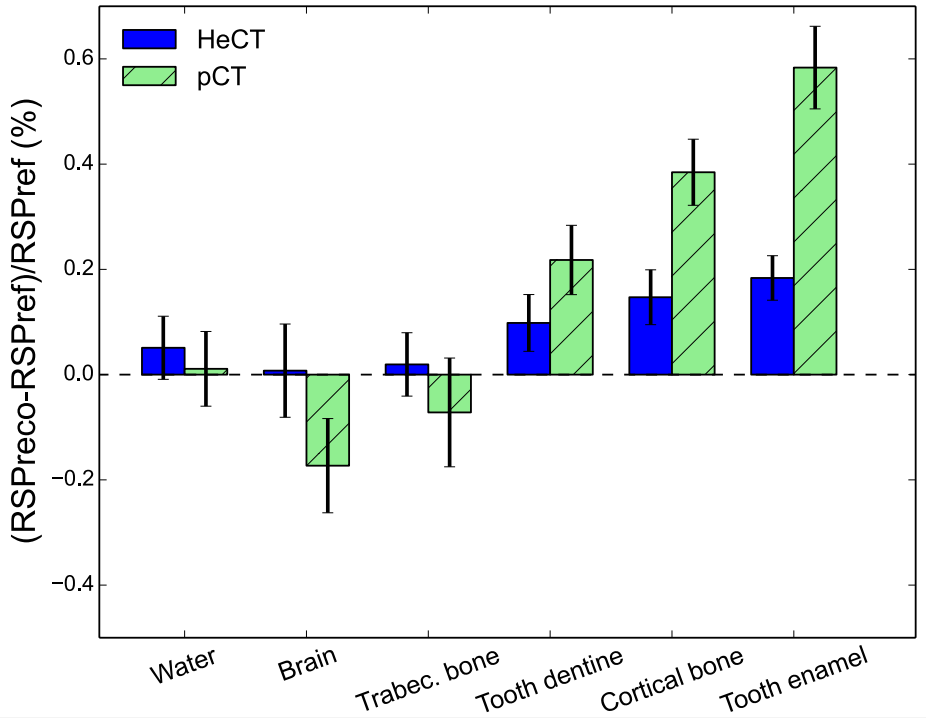
IP1 phantom





- 90 projections, 4º step
- $2x10^6$ primaries per projection
- 1.25 cm slice thickness

- 256x256 pixels, 0.66 mm
- TVS-DROP algorithm*
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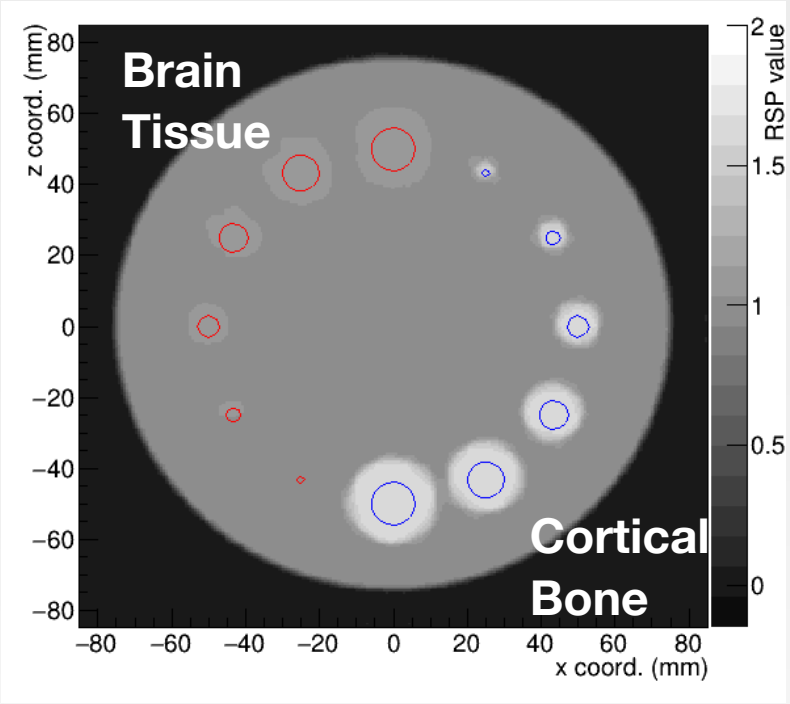
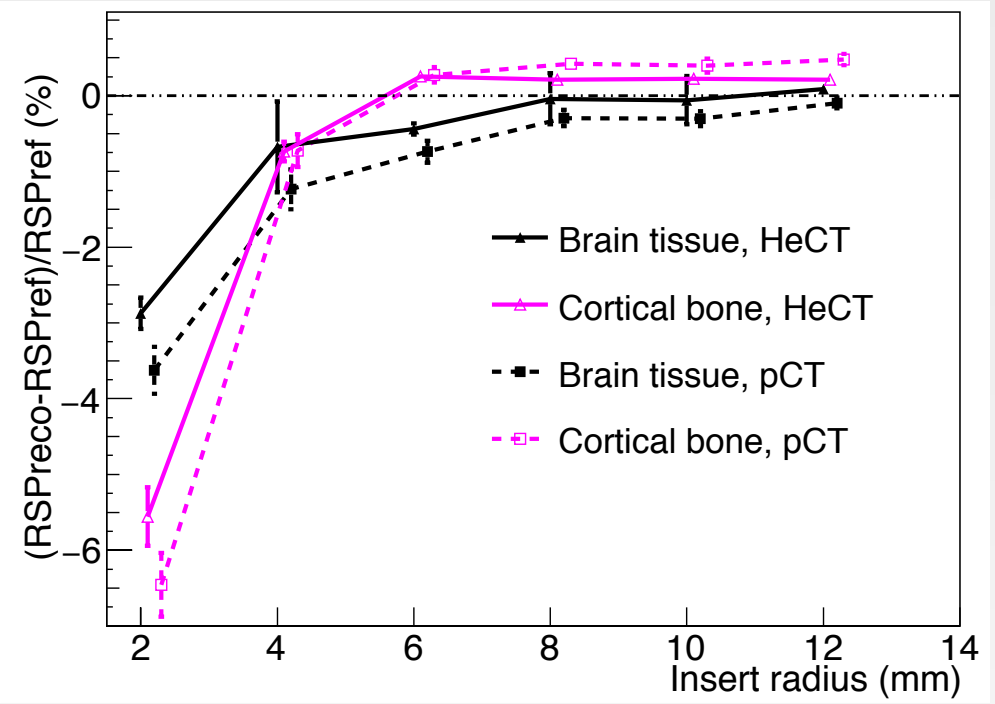
IP2 phantom





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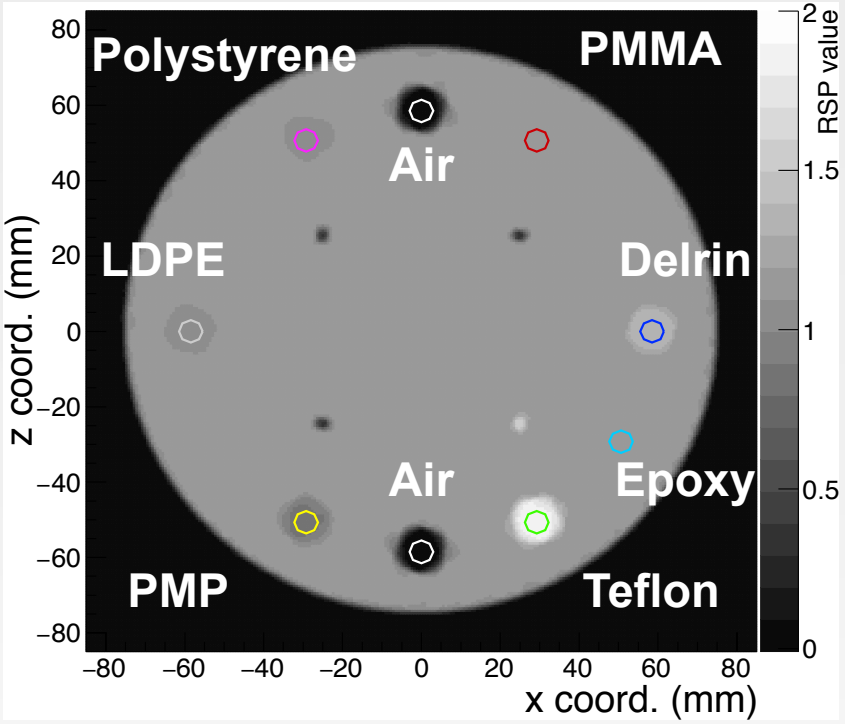
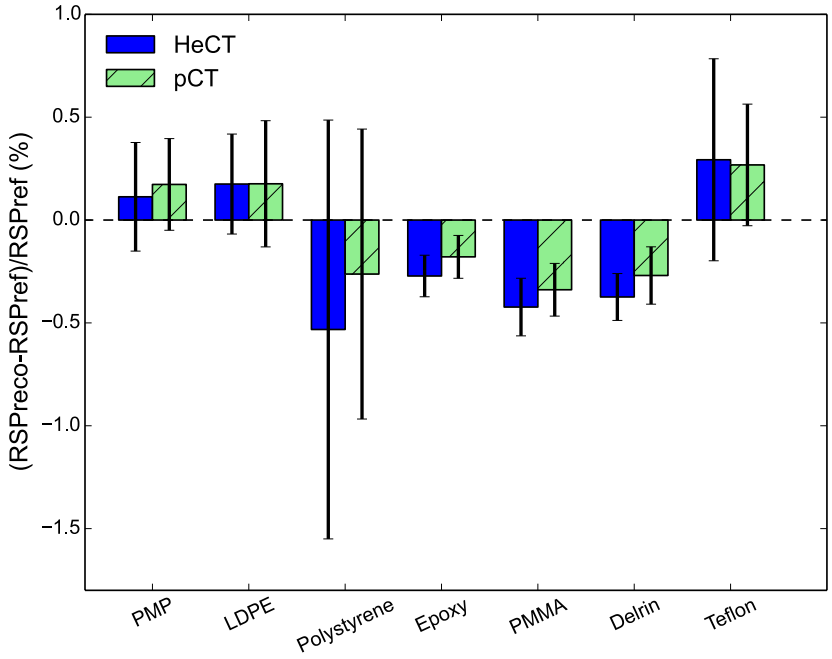
IP1 phantom





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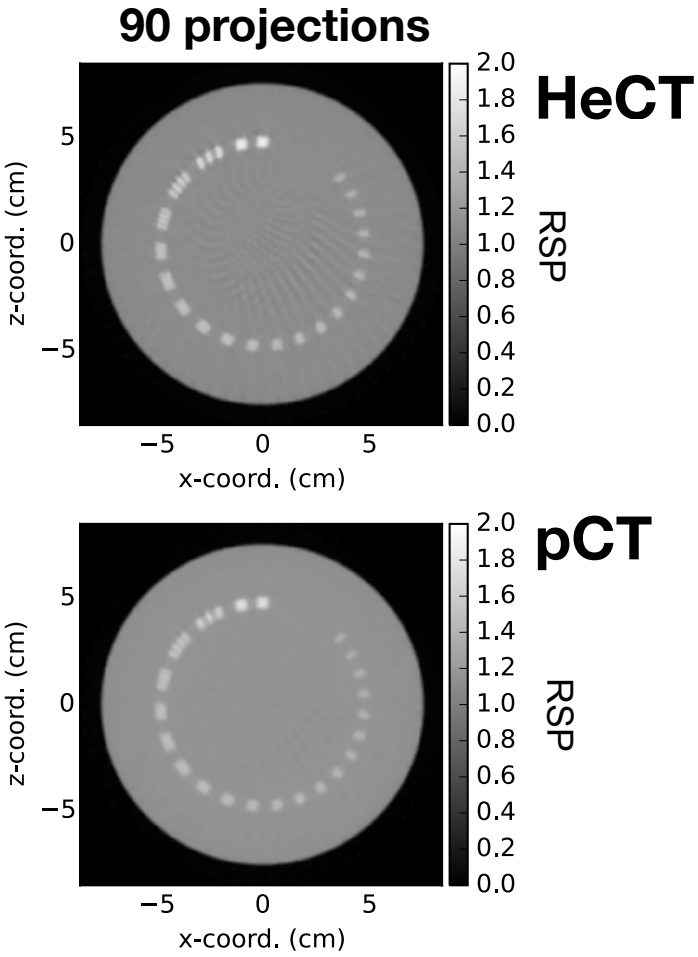
Spatial Resolution: CTP528



$2x10^6$ primaries per projection

1.25 mm slice thickness

512x512 pixels, 0.33 mm

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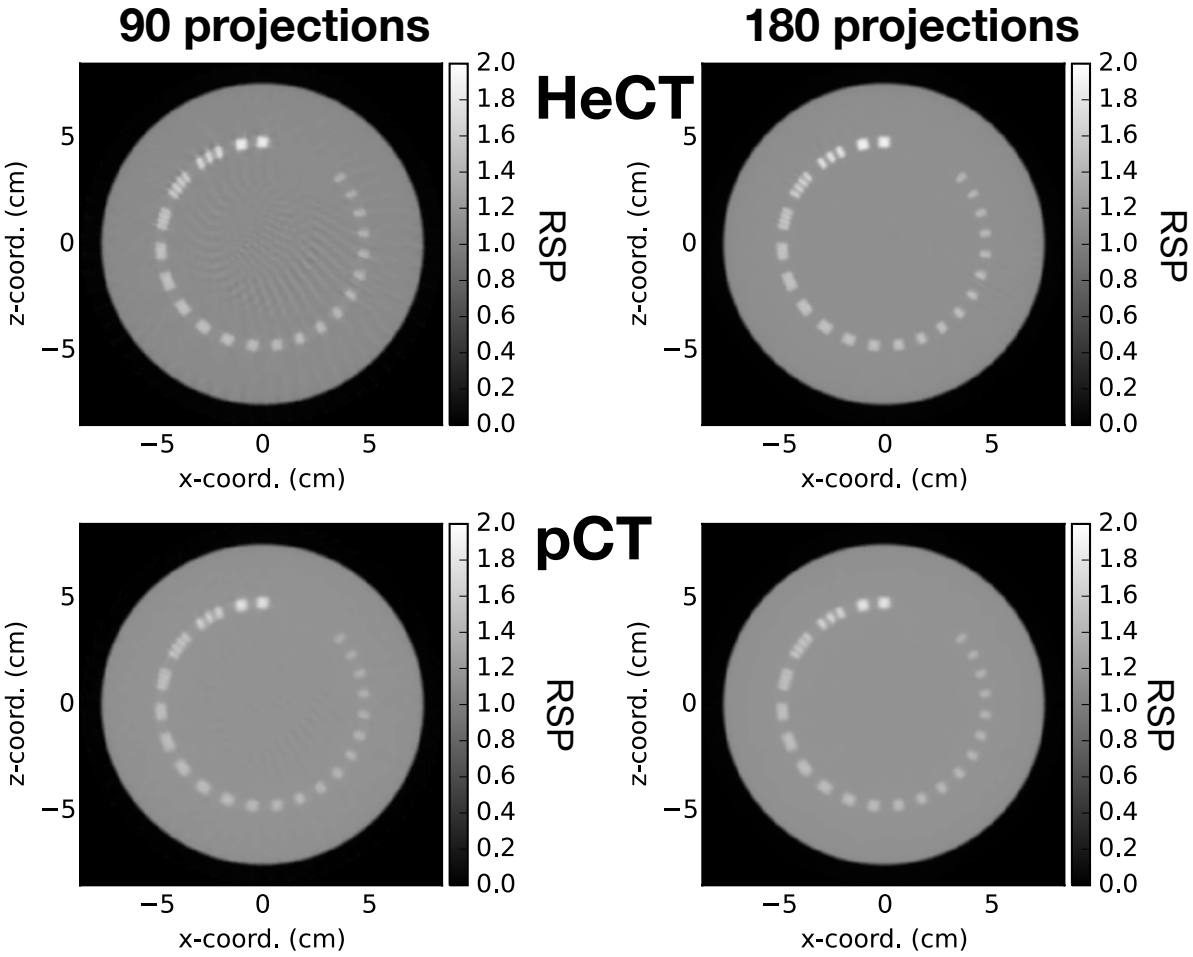

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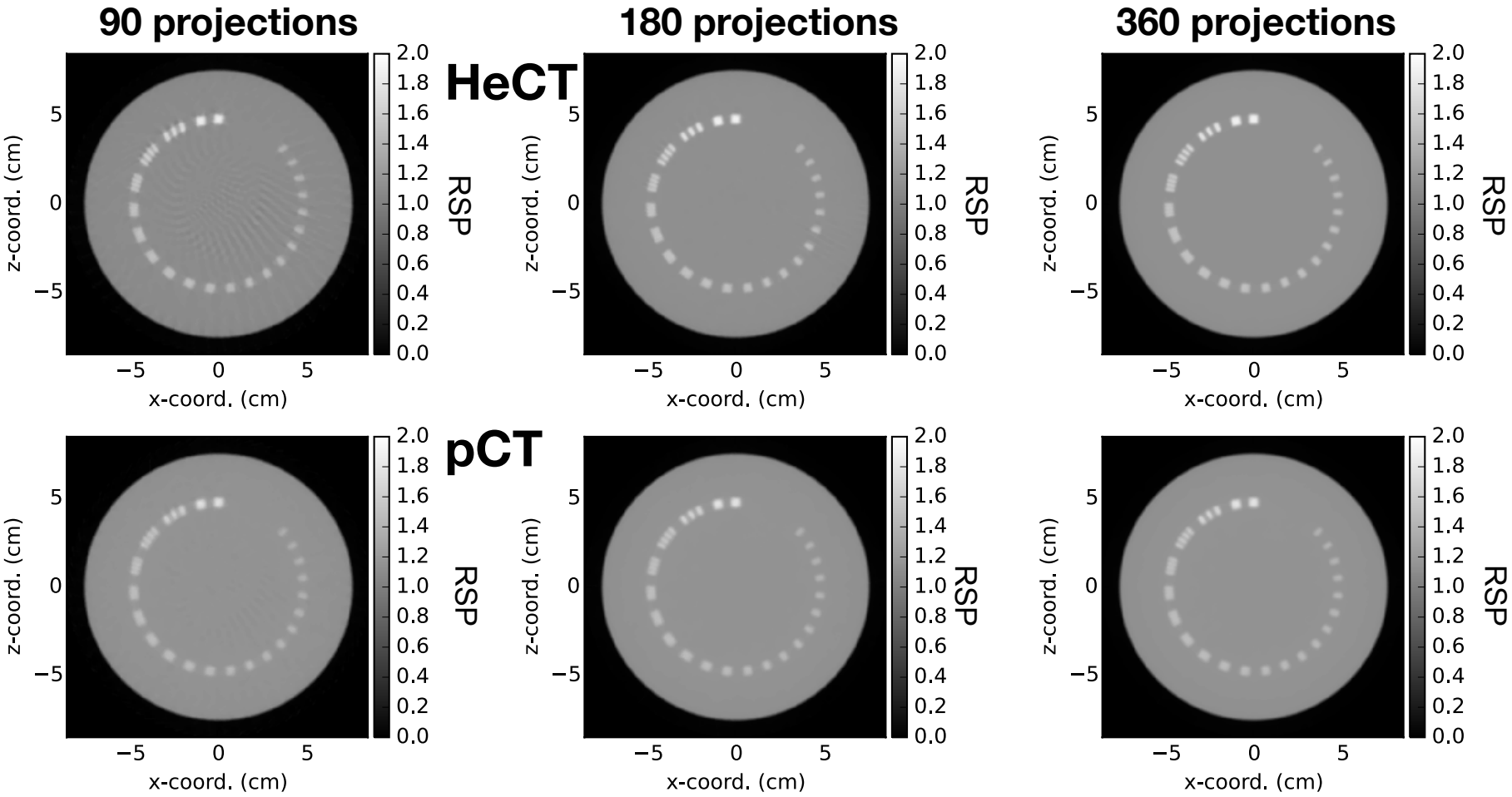

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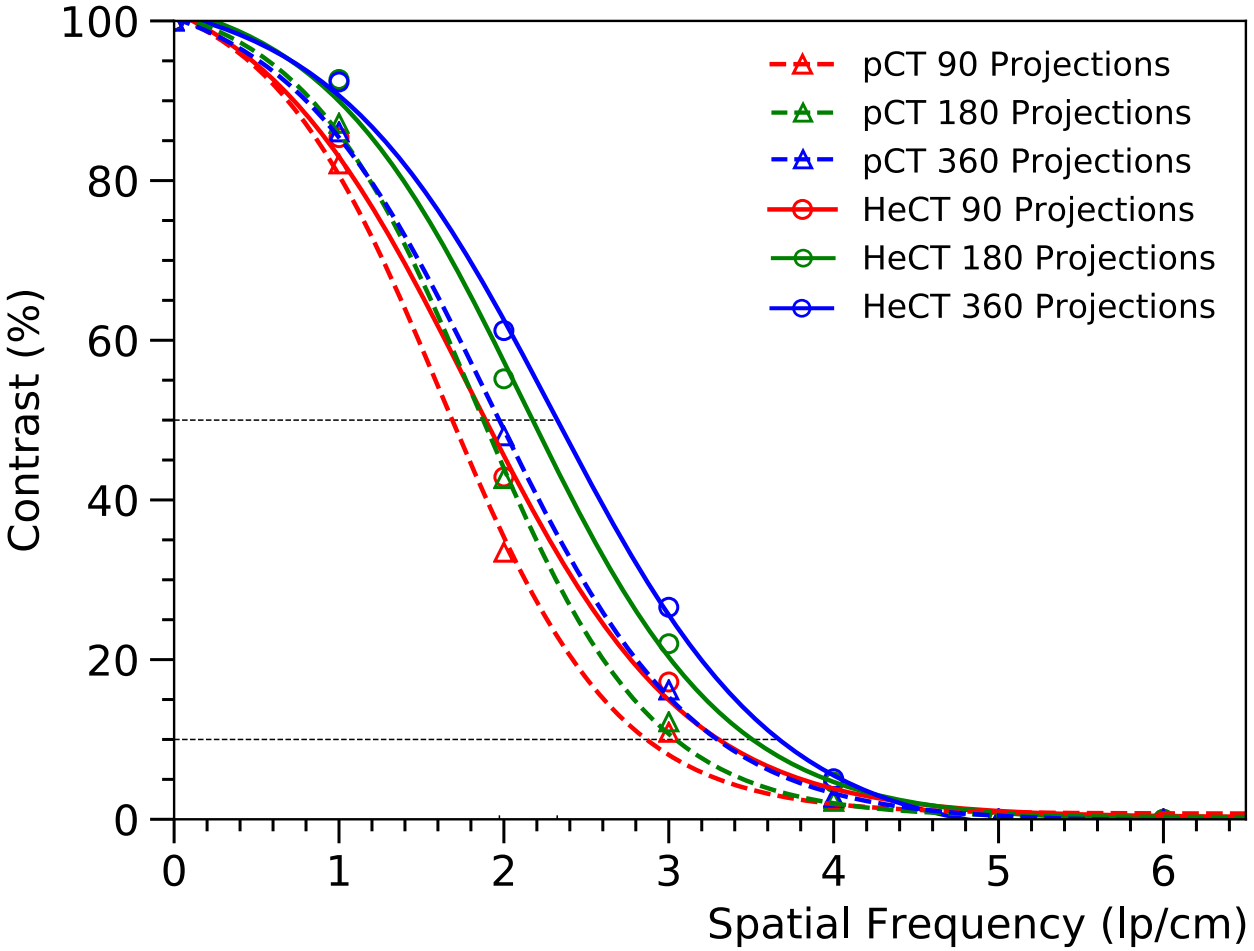

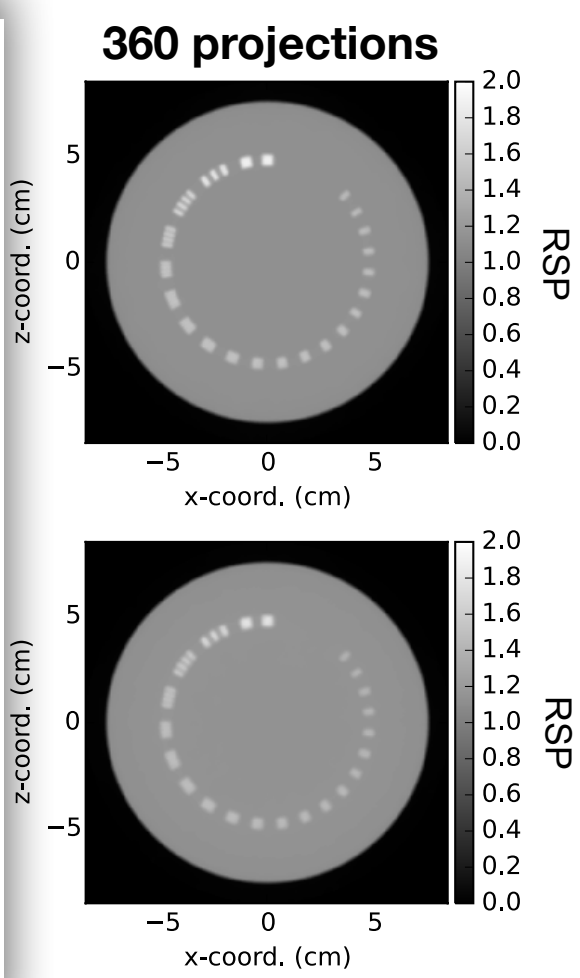

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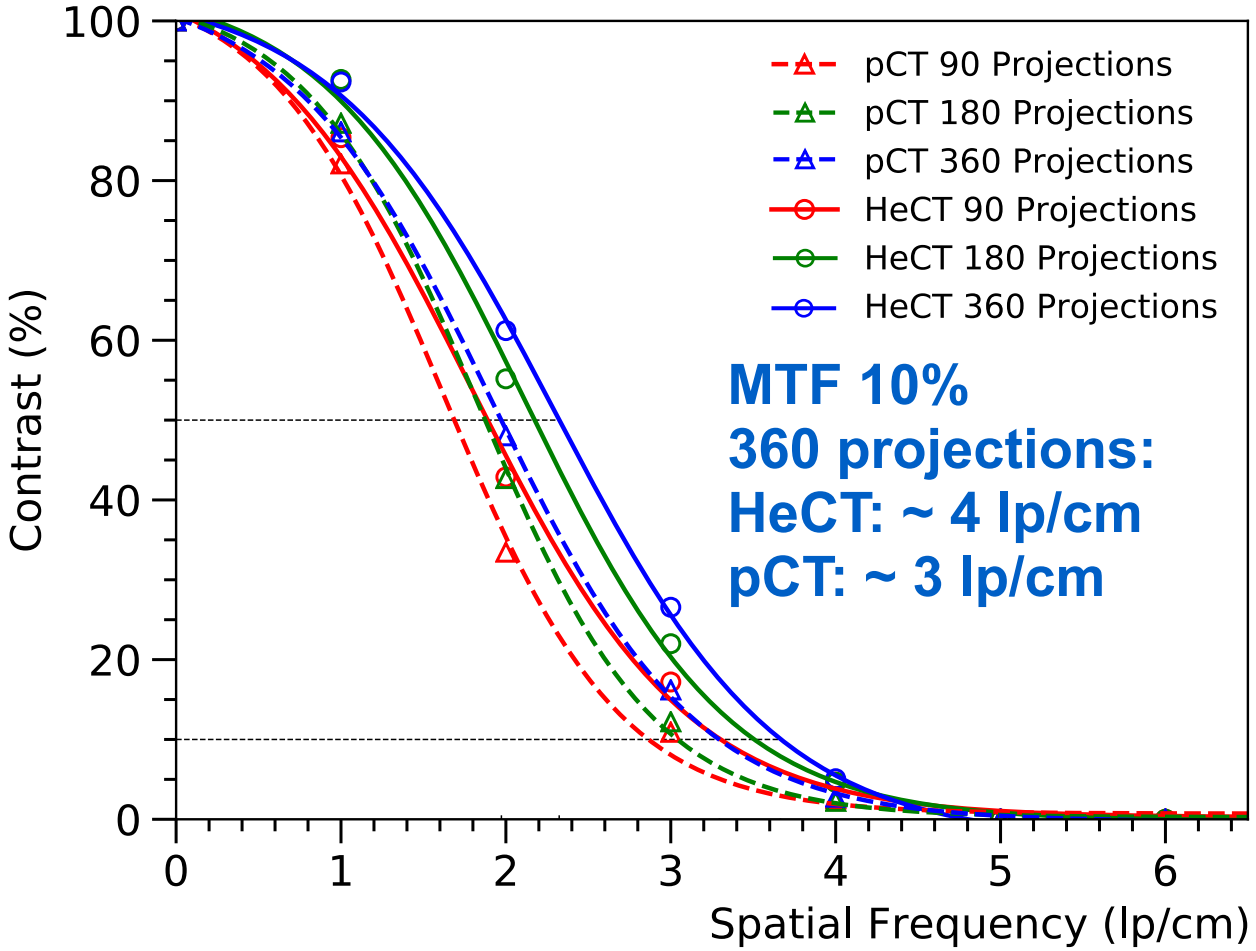
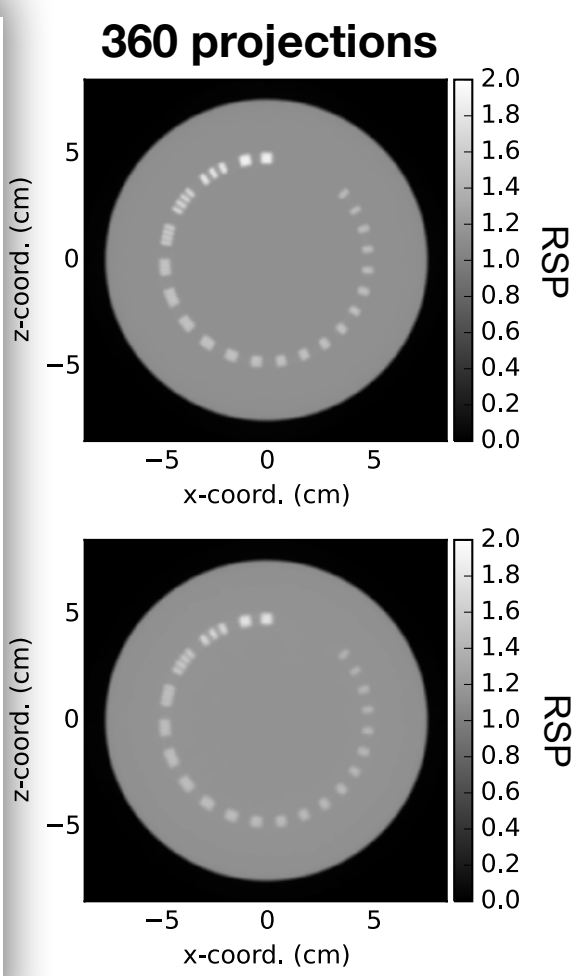
Spatial Resolution: CTP528





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1.25 mm slice thickness

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Fragment filtering

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Bergen pCT collaboration

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Bergen pCT collaboration

UNIVERSITY OF BERGEN

Organization

- UiB, HiB, HUS
- Utrecht University
- DKFZ Heidelberg
- Wigner Research Centre for Physics, Budapest

Financing

- 44 MNOK,
  5 years (2017-2021)

Status

- Finishing the optimization of the design
- Start mass-production of ALPIDE chips
- Sensor characterization

Bergen pCT collaboration

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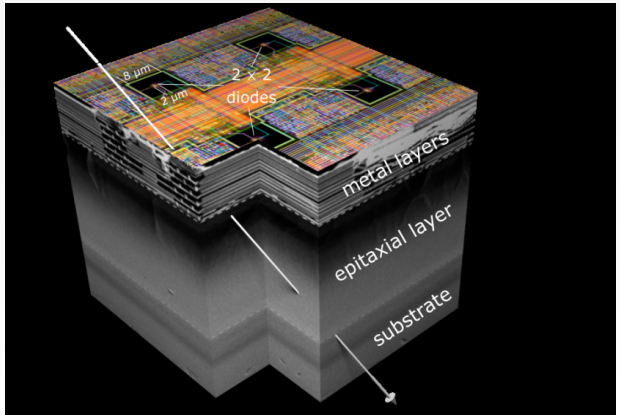
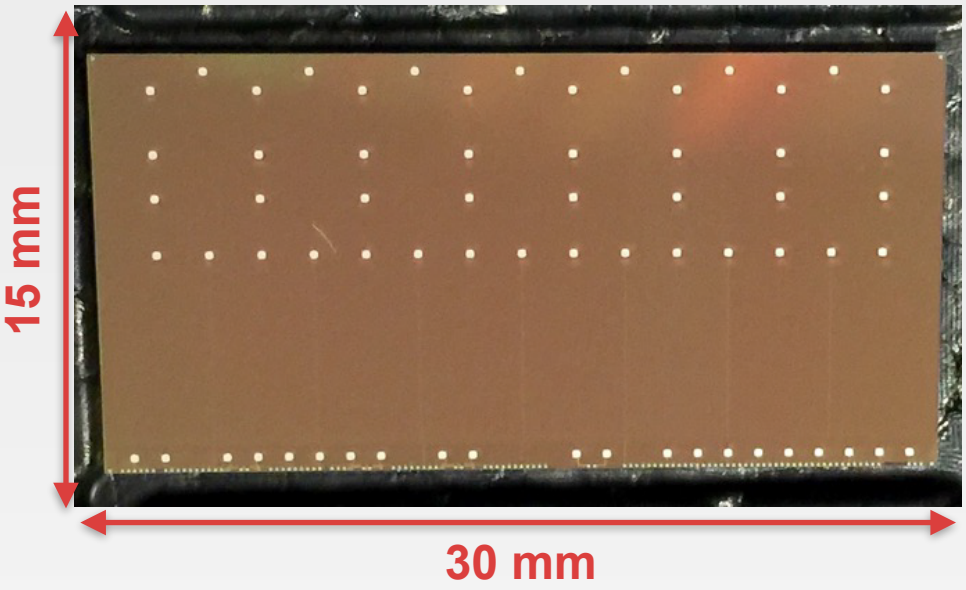
Norwegian government has decided to build two particle therapy facilities (Oslo, Bergen), to be operational by 2022 rep. 2025

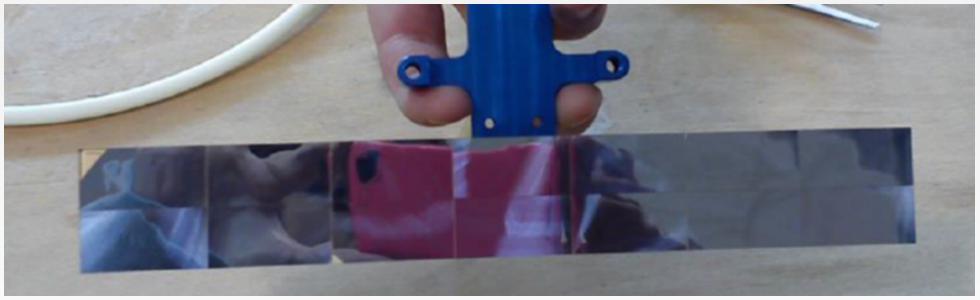
Pixel sensor

ALPIDE chip

- sensor for the upgrade of the inner tracking system of the ALICE experiment at CERN
- chip size ≈ 3x1.5 cm^2, pixel size ≈ 28 μm, integration time ≈ 4 μs
- on-chip data reduction (priority encoding per double column)







Design team:
CCNU Wuhan, CERN Geneva, YONSEI Seoul, INFN Cagliari, INFN Torino, IPHC Strasbourg, IRFU Saclay, NIKHEF Amsterdam

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Optimization of the design

Geometry

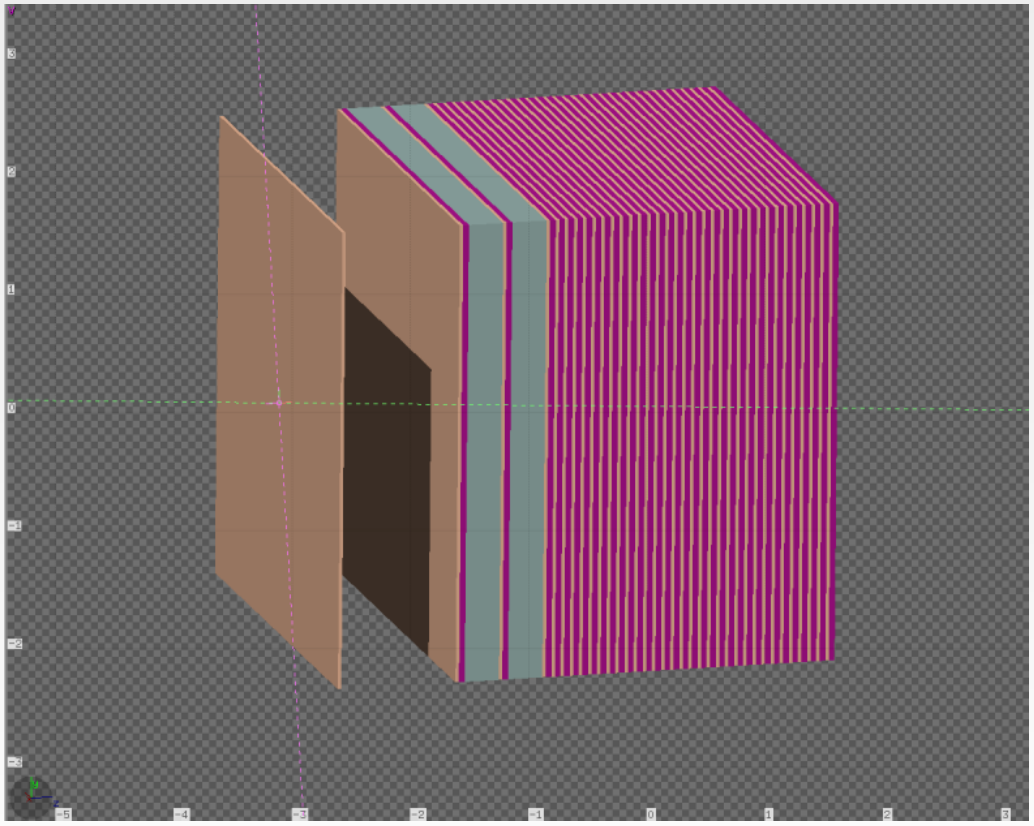
- front area: 27 cm x 15(18) cm

longitudinal segmentation

- number of sensitive resp. absorber layers: 41

absorber

- energy degrader, mechanical carrier,
- cooling medium
- material choice: Al
- thickness: 3.5 mm



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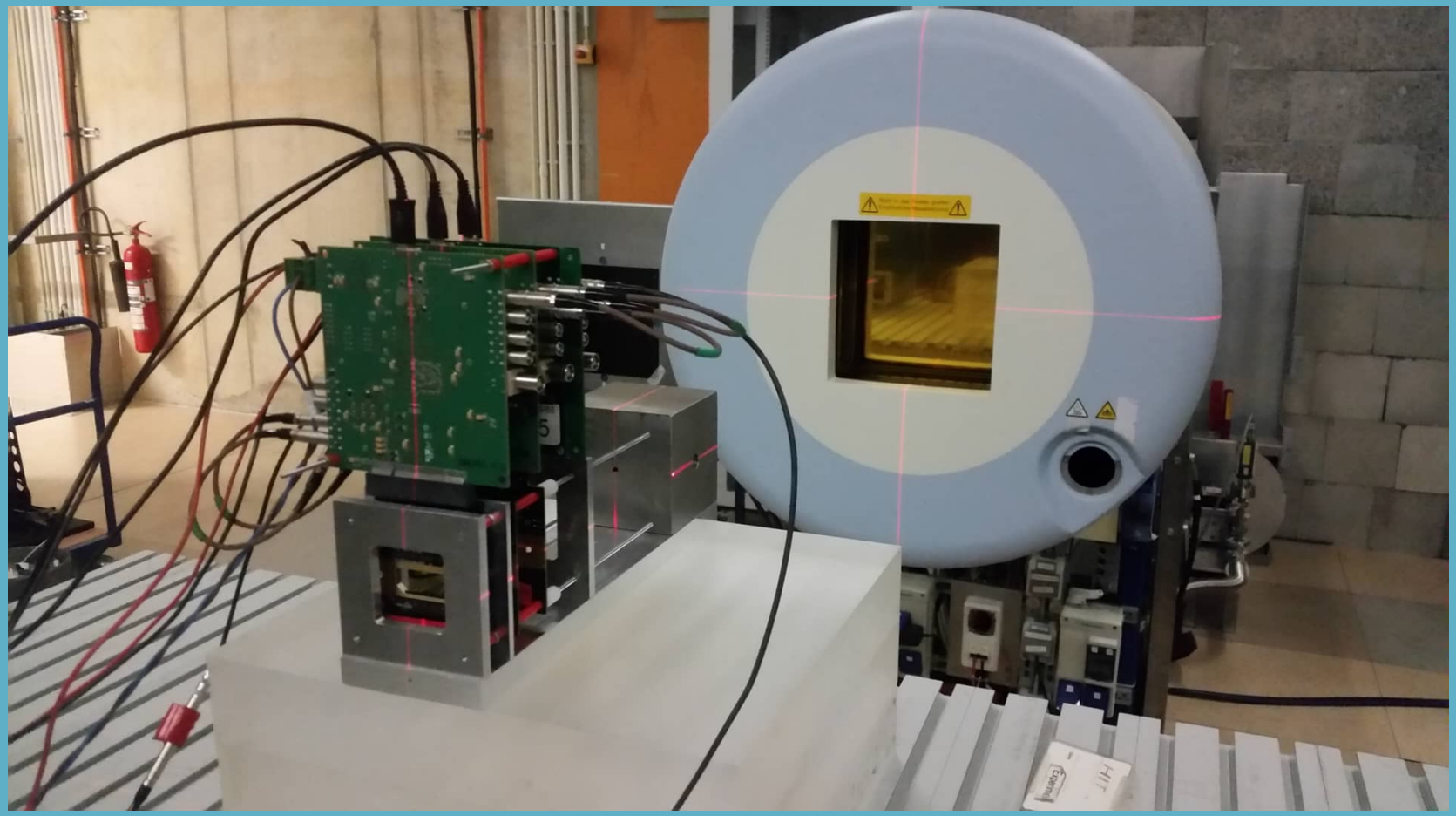
Experiment at HIT with 3 Alpide chips

July 2018



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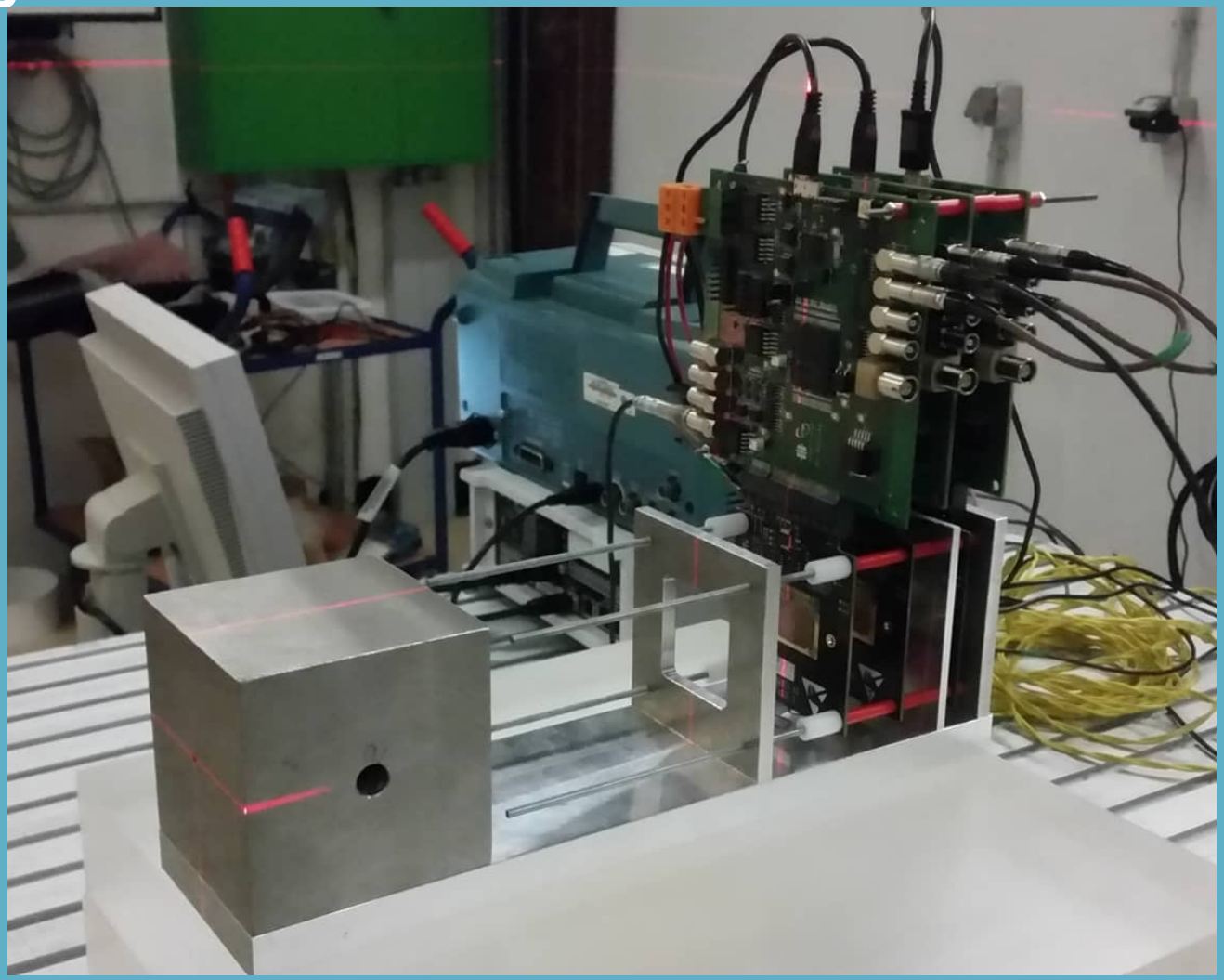

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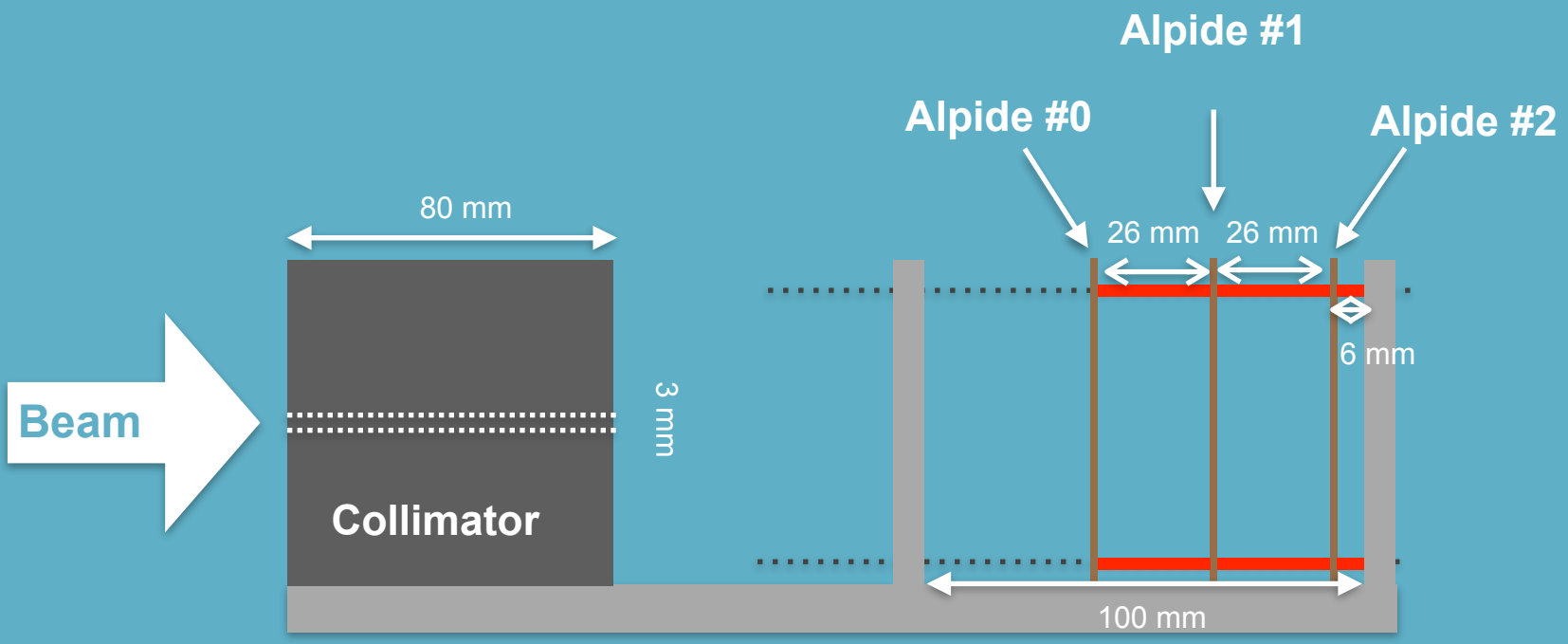

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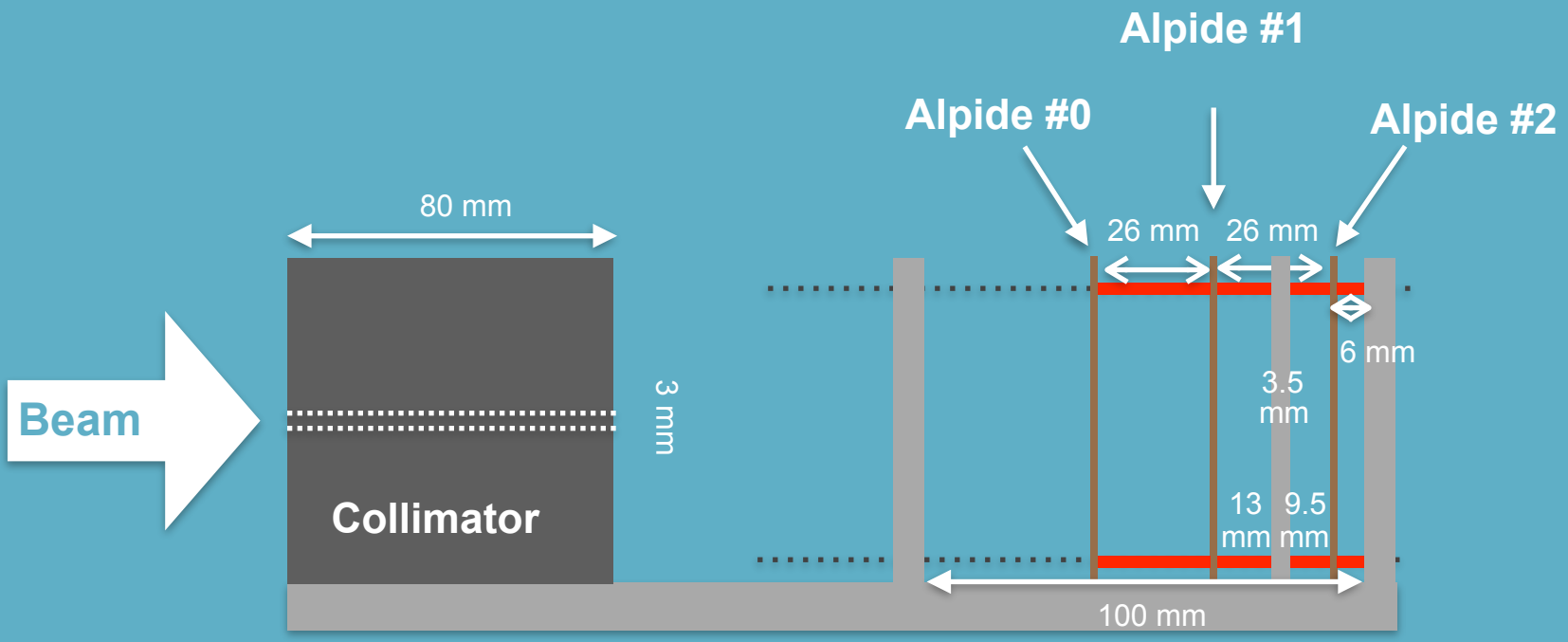

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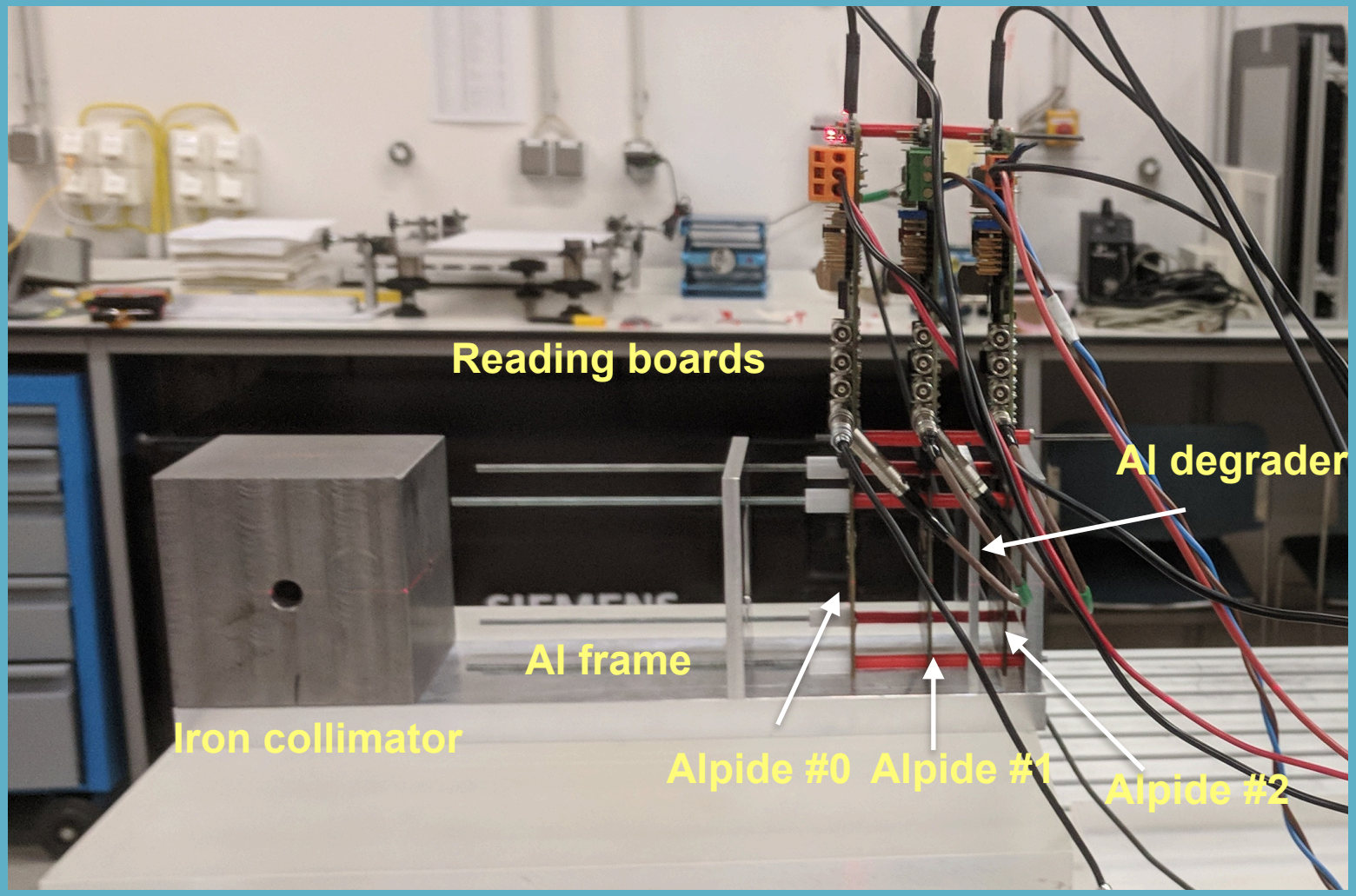


Helium ions

5 Energies (FWHM)

- 220.5 MeV/u (10.1 mm)
- 200.38 MeV/u (10.2 mm)
- 50.57 MeV/u (20.6 mm)
- 100.19 MeV/u (12.9 mm)
- 150.11 MeV/u (11.1 mm)

Triggering

- 10 μs, 30 μs

Collimator

- 3 mm, 10 mm

Beam

- 12 s extraction time
- ~100 ±50 kHz intensity hitting the collimator

Protons

5 Energies (FWHM)

- 221.06 MeV (12.6 mm)
- 200.11 MeV (12.8 mm)
- 48.12 MeV (32.7 mm)

Triggering

- 30 μs

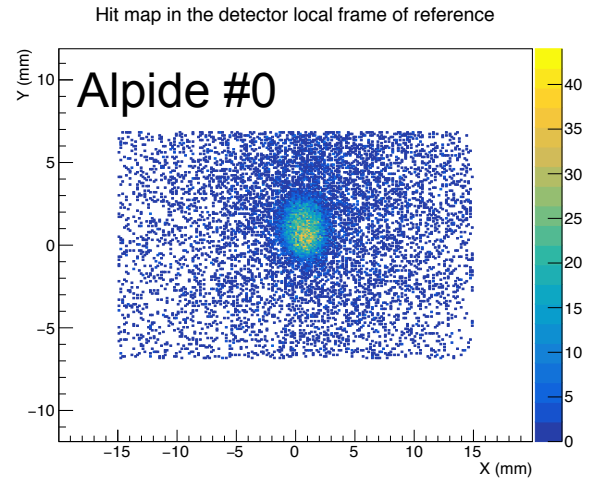
Collimator

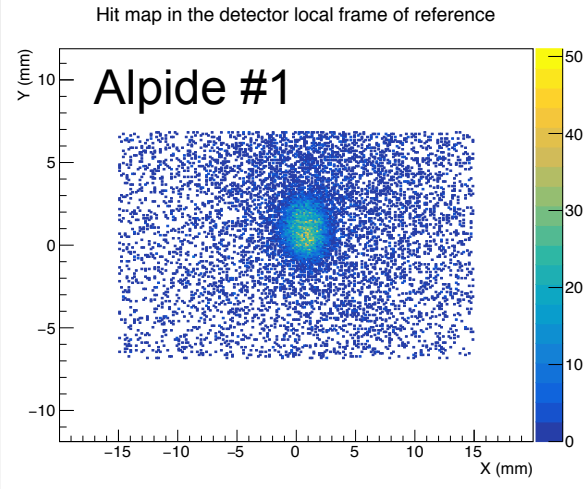
- 3 mm

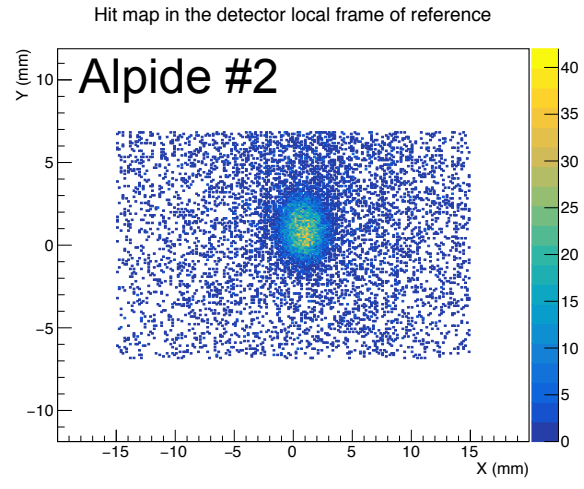
Beam

- 12 s extraction time
- ~100 ±50 kHz intensity hitting the collimator

Initial results - Alignment







- Energy (FWHM): 220.5 MeV/u (10.1 mm)
- Triggering:10 μs

- Collimator: 3 mm
- 96.5% tracking efficiency in 3 layers

- 15% of events have «ghosts»
- ~80 kHz ^{4}He rate

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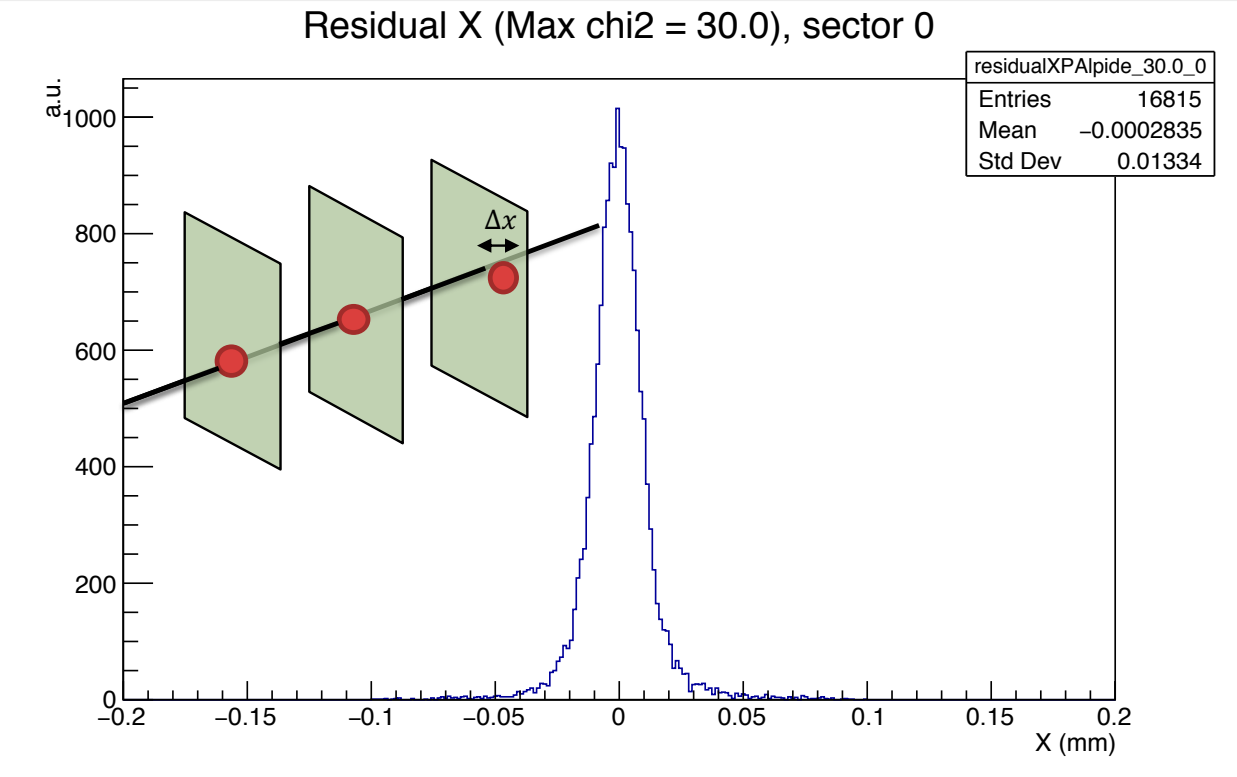
Initial results - Alignment



- Energy (FWHM): 220.5 MeV/u (10.1 mm)
- Triggering:10 μs

- Collimator: 3 mm
- 96.5% tracking efficiency in 3 layers

- 15% of events have «ghosts»
- ~80 kHz ^{4}He rate

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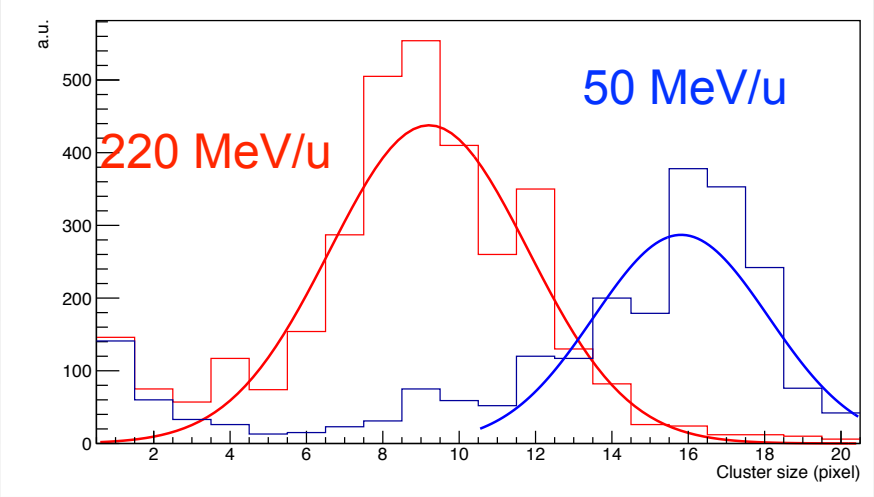
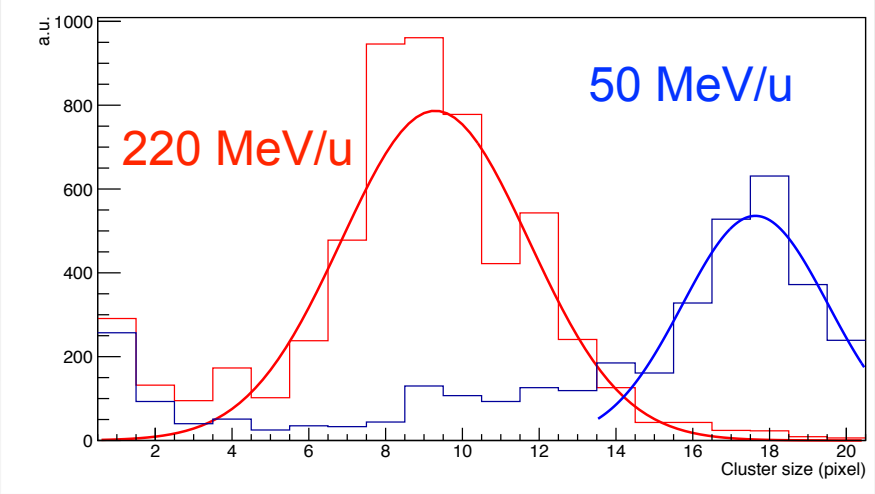
Initial results - Cluster size on the 3rd chip

without Al degr.



with Al degr.



220MeV/u

- mean:9.21
- sigma: 2.60

50 MeV/u

- mean:15.81
- sigma: 2.28

220MeV/u

- mean: 9.29
- sigma: 2.44

50 MeV/u

- mean: 17.63
- sigma:1.89

- Triggering:10 μs
- Collimator: 3 mm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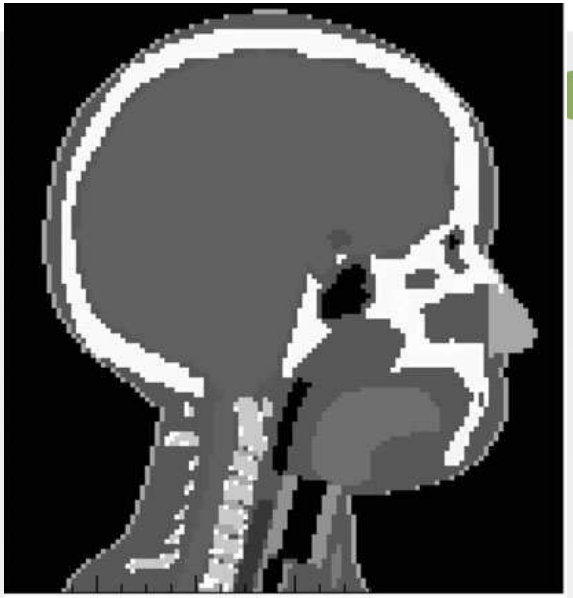
BERGENSIS

Human-like phantoms

- Digital head phantom[1]:
  10-year old human female
  $90 \times 114 \times 10^3$ cubic voxels
  $2 \times 2 \times 2$ mm^3

  Each voxel has a specific material composition and density

  Reference RSP values calculated for each material[2]
- CIRS HN715:
  Anthropomorphic pediatric head phantom
  (CIRS, Norfolk, Virginia, USA)



[1]Lee et al. 2010 [2]Piersimoni et al. 2017

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